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(45) **Date of Patent:** **Jul. 17, 2012**

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,075,256	A	6/2000	Kaifu et al.	257/53
6,828,539	B1	12/2004	Kuwabara	250/208.1
6,952,015	B2	10/2005	Kameshima	250/370.11
6,952,464	B2	10/2005	Endo	378/98.11

(Continued)

FOREIGN PATENT DOCUMENTS

EP 1 176 814 1/2002
(Continued)

OTHER PUBLICATIONS

International Search Report mailed Mar. 6, 2007, for International Application No. PCT/JP2006/324121.

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(57) **ABSTRACT**

To provide a radiation imaging apparatus capable of restraining the change of image qualities due to the change of sensitivities of an MIS-type photoelectric conversion element and its control method. Therefore, an MIS-type photoelectric conversion element **217** is set to a saturation state before performing radiation imaging. As means for realizing the above mentioned, a light source **601**, power supply **603** for making the light source **601** emit light, and switch **605** are provided. The light source **601** can use a light source capable of discharging the light having a wavelength which can be detected by a photoelectric conversion layer **209** at optional timing. For example, it is possible to use a light source in which a plurality of LEDs or cold cathode ray tubes are arranged, a light guide plate is combined with an LED or cold cathode ray tube, or an EL device.

8 Claims, 20 Drawing Sheets

(58) **Field of Classification Search** 250/370.09
See application file for complete search history.

U.S. PATENT DOCUMENTS

6,965,111	B2 *	11/2005	Endo	250/370.11
6,985,555	B2	1/2006	Endo	378/98.11
7,002,157	B2	2/2006	Kameshima	250/370.11
7,012,260	B2	3/2006	Endo	250/370.11
7,138,639	B2	11/2006	Kameshima	250/370.11
7,154,099	B2	12/2006	Endo	250/370.11
7,227,926	B2	6/2007	Kameshima et al.	378/98.9
7,408,167	B2	8/2008	Kameshima et al.	250/370.09
7,421,063	B2	9/2008	Takenaka et al.	378/116
7,476,027	B2	1/2009	Takenaka et al.	378/207
7,514,663	B2	4/2009	Yagi et al.	250/208.1
7,550,733	B2	6/2009	Endo et al.	250/370.09
7,564,038	B2	7/2009	Endo et al.	250/370.11
7,629,587	B2	12/2009	Yagi et al.	250/370.15
7,696,484	B2	4/2010	Yokoyama et al.	250/370.09
7,724,874	B2	5/2010	Kameshima et al.	378/98.12
7,777,167	B2 *	8/2010	Takeda et al.	250/205
7,839,977	B2	11/2010	Kameshima et al.	378/116
2002/0024016	A1	2/2002	Endo	250/370.11
2003/0038242	A1	2/2003	Endo	250/370.14
2004/0079891	A1	4/2004	Sato et al.	250/370.12
2005/0109927	A1	5/2005	Takenaka et al.	250/252.1
2005/0199834	A1	9/2005	Takenaka et al.	250/580

2005/0200720	A1	9/2005	Kameshima et al.	348/220.1
2005/0220269	A1	10/2005	Endo et al.	378/114
2005/0264665	A1	12/2005	Endo et al.	348/308
2006/0119719	A1	6/2006	Kameshima	348/308
2006/0192130	A1	8/2006	Yagi	250/370.14
2006/0289774	A1	12/2006	Endo et al.	250/370.09
2007/0040099	A1	2/2007	Yokoyama et al.	250/208.1
2007/0069144	A1	3/2007	Kameshima	250/370.09
2007/0080299	A1	4/2007	Endo et al.	250/370.09
2007/0096032	A1	5/2007	Yagi et al.	250/370.11
2007/0125952	A1	6/2007	Endo et al.	250/369
2007/0131843	A1	6/2007	Yokoyama et al.	250/205
2007/0183573	A1	8/2007	Kameshima et al.	378/98.9
2007/0210258	A1	9/2007	Endo et al.	250/370.09

FOREIGN PATENT DOCUMENTS

EP	1 267411	12/2002
EP	1 394 567	3/2004
JP	6-326286	11/1994
JP	2002-40144	2/2002
JP	2003-78124	3/2003
JP	2004-146769	5/2004
JP	2005-6790	1/2005

* cited by examiner

FIG. 1

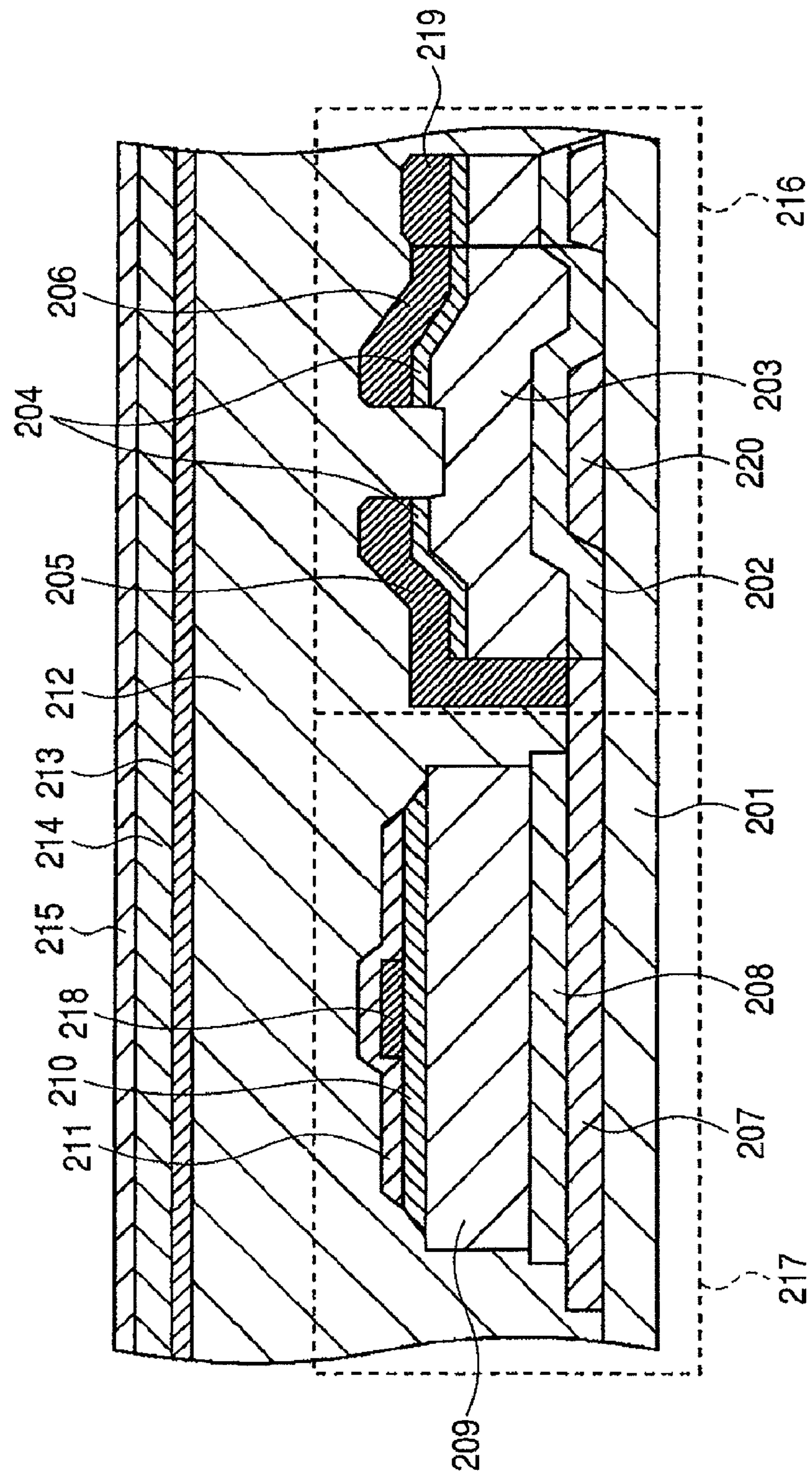


FIG. 2A
PHOTOELECTRIC
CONVERSION MODE

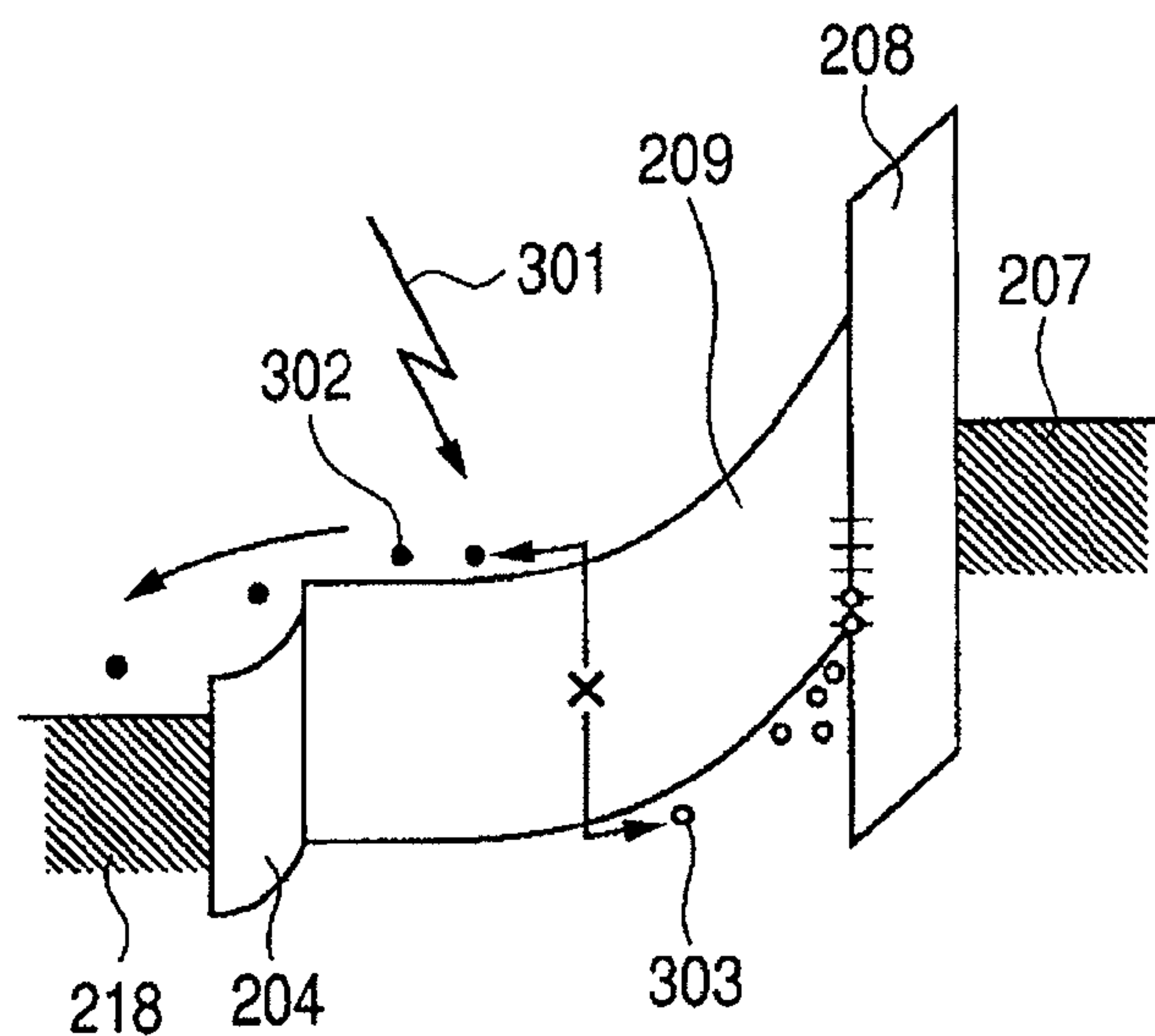


FIG. 2B
SATURATED STATE

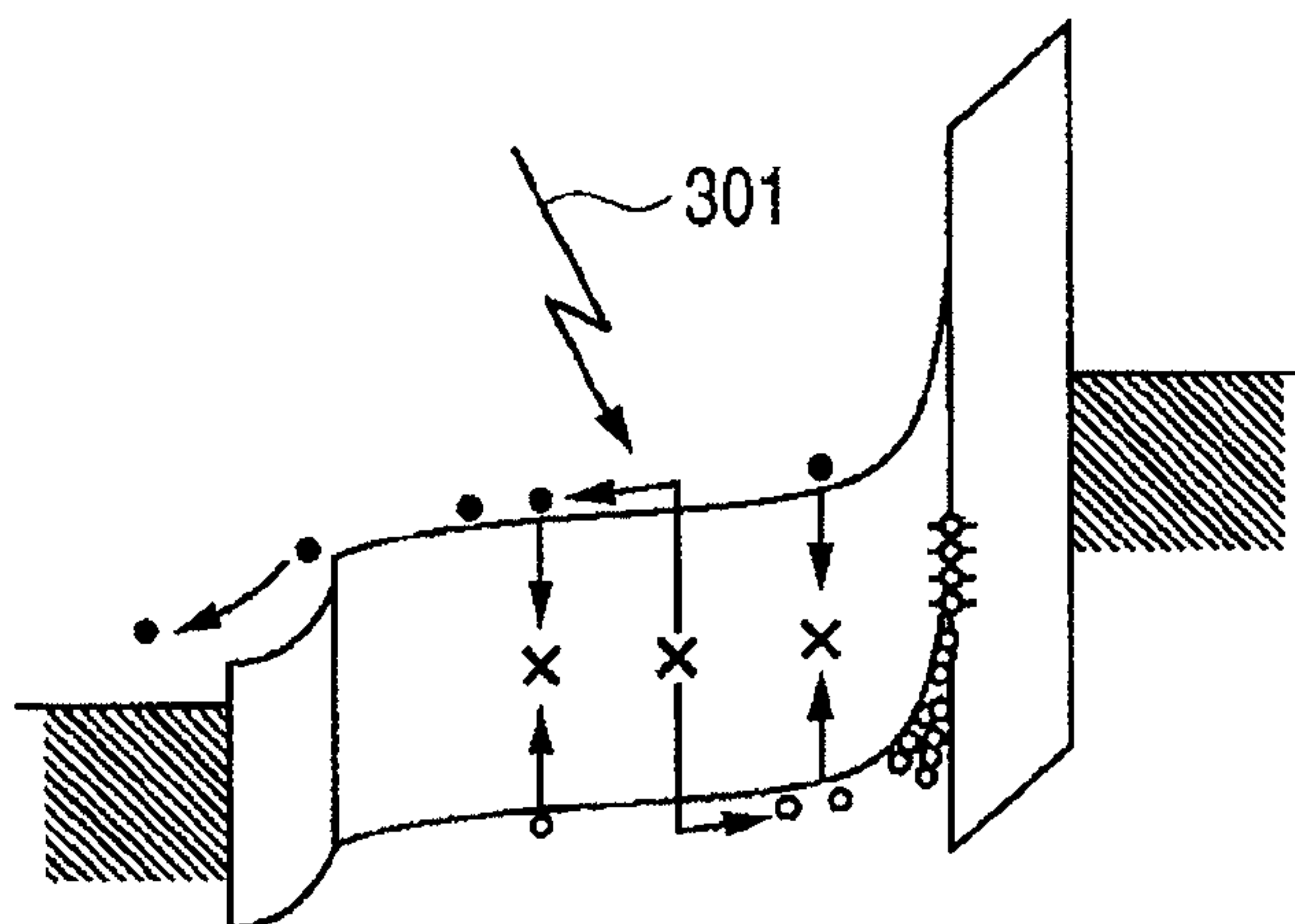


FIG. 2C
REFRESH MODE

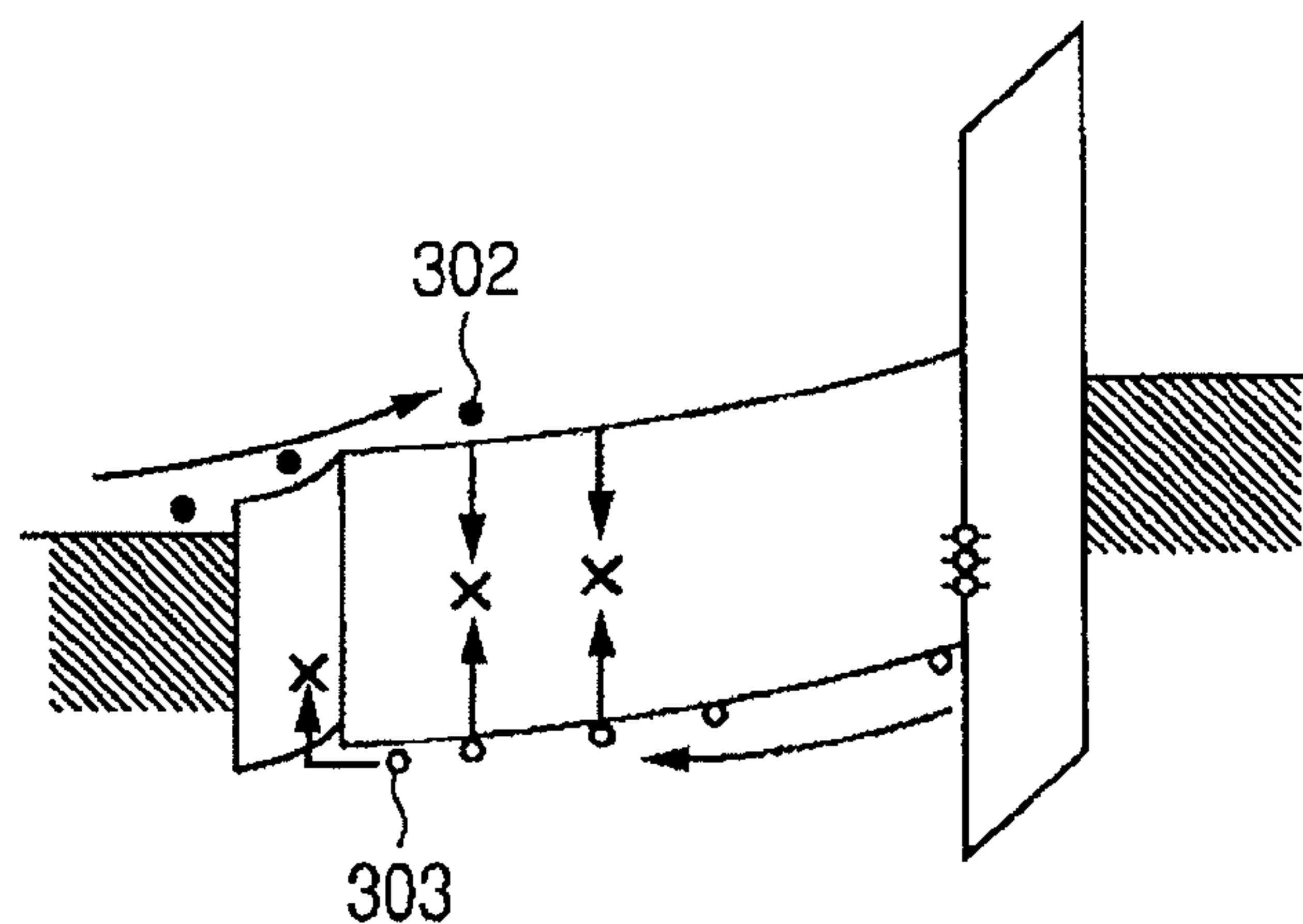


FIG. 3

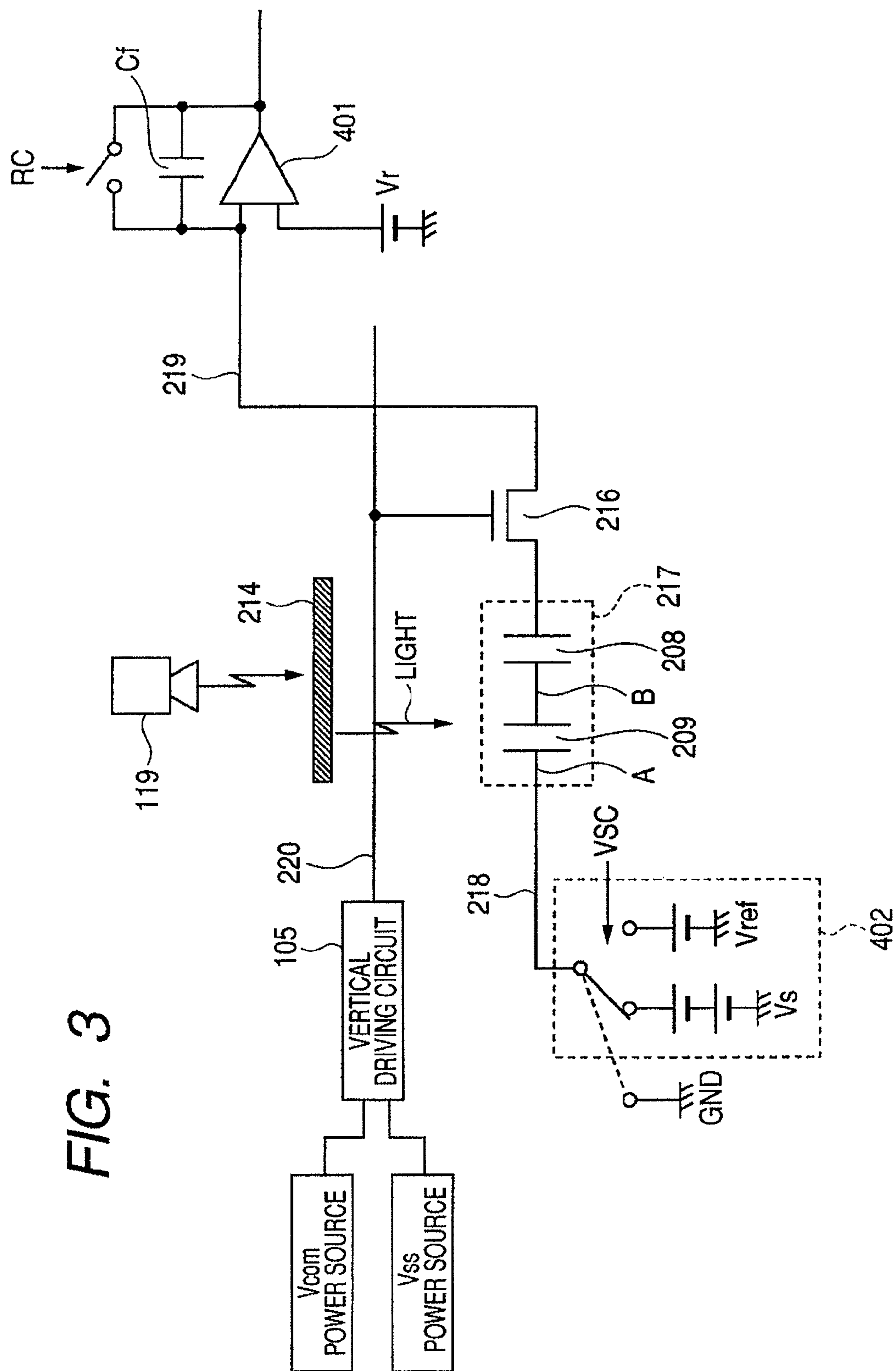


FIG. 4

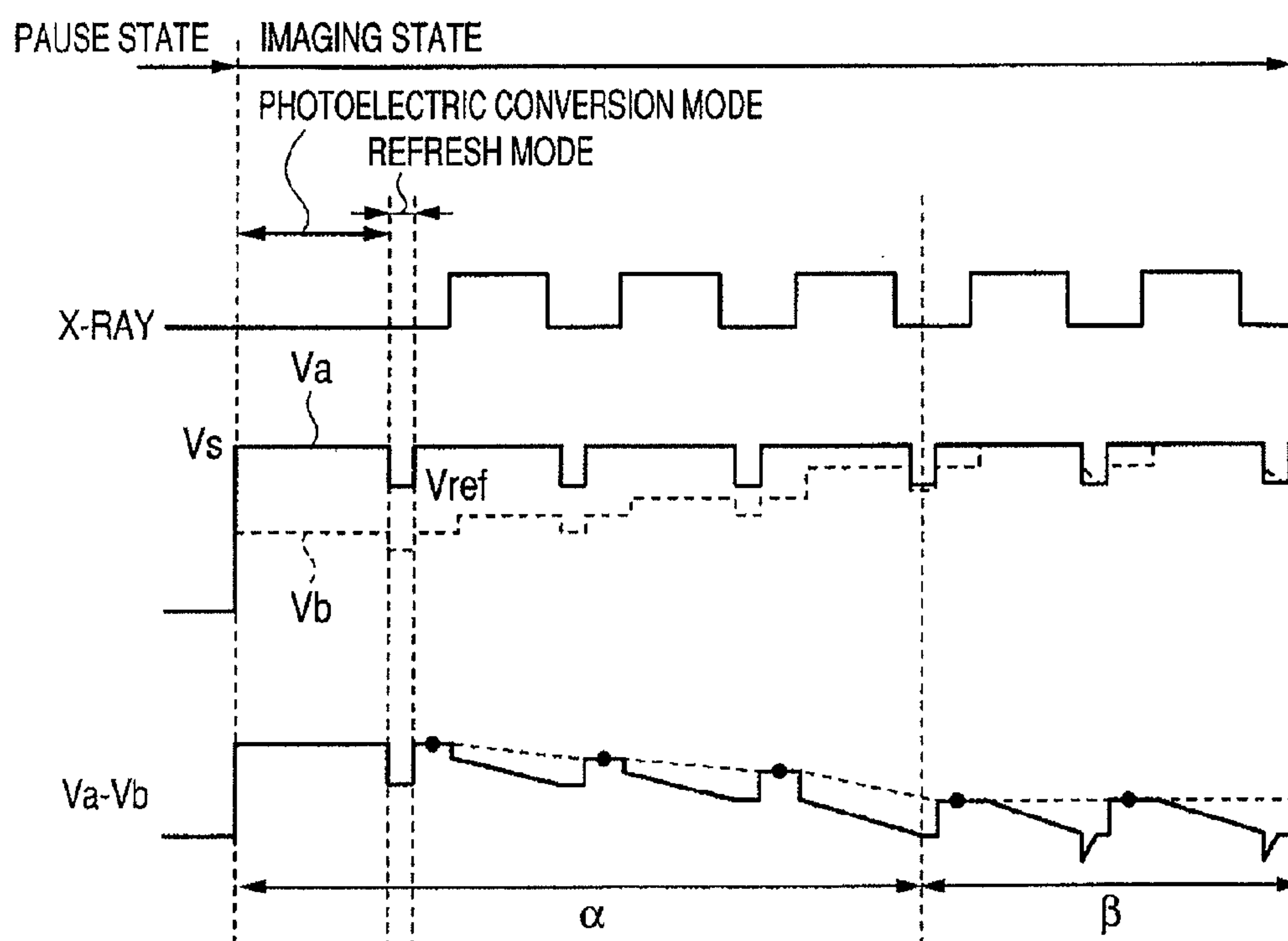


FIG. 5

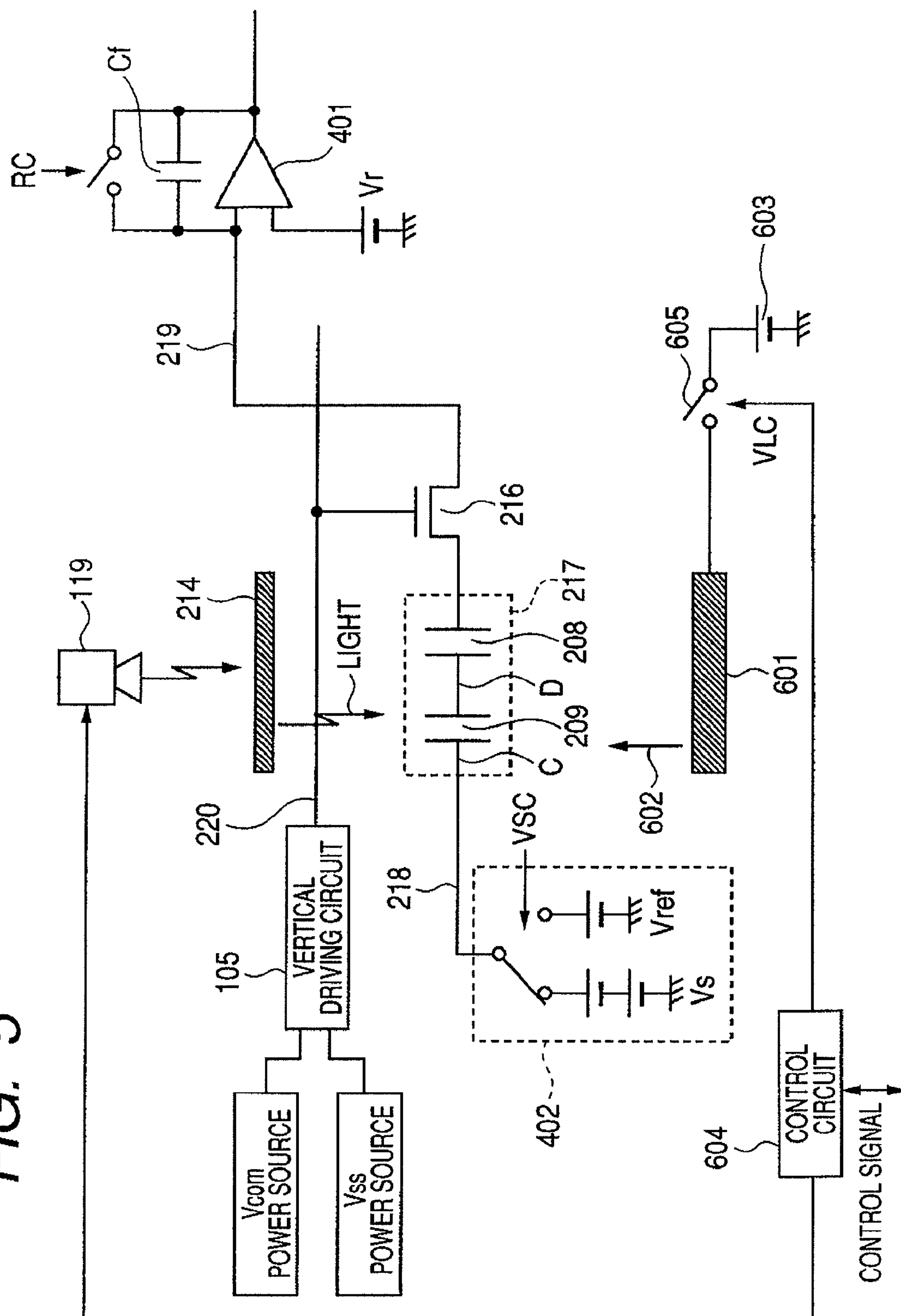


FIG. 6

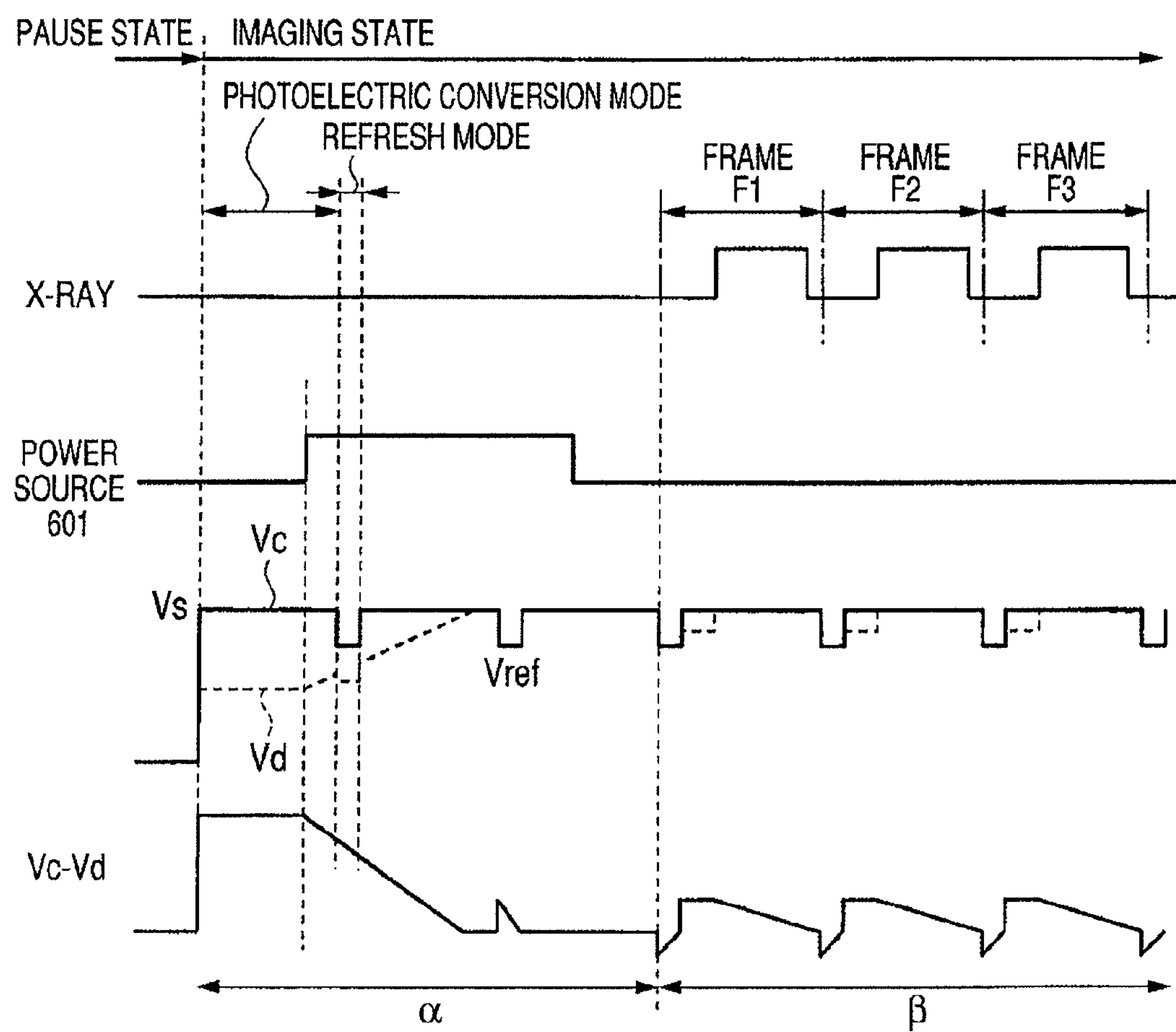


FIG. 7

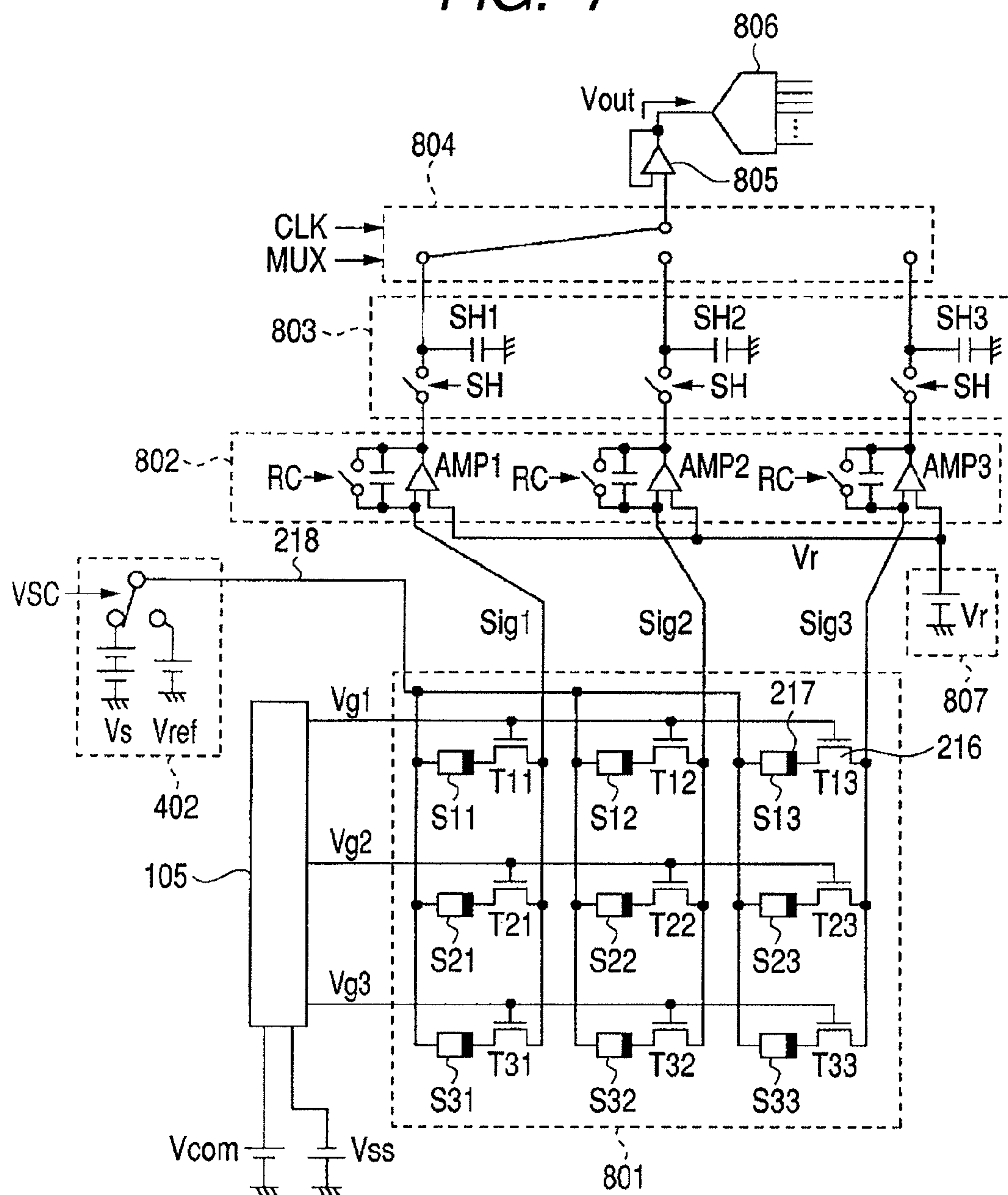


FIG. 8

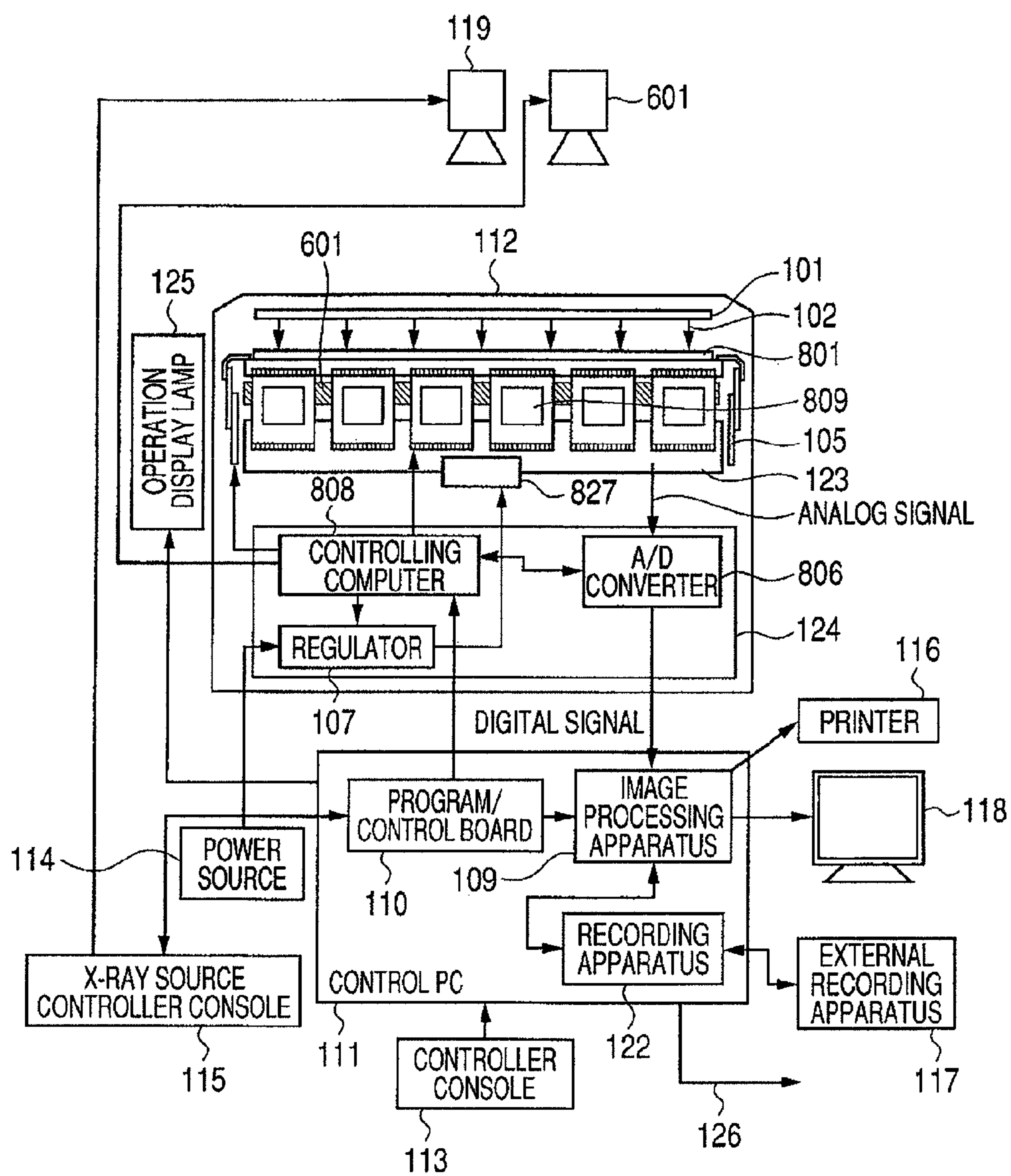


FIG. 9

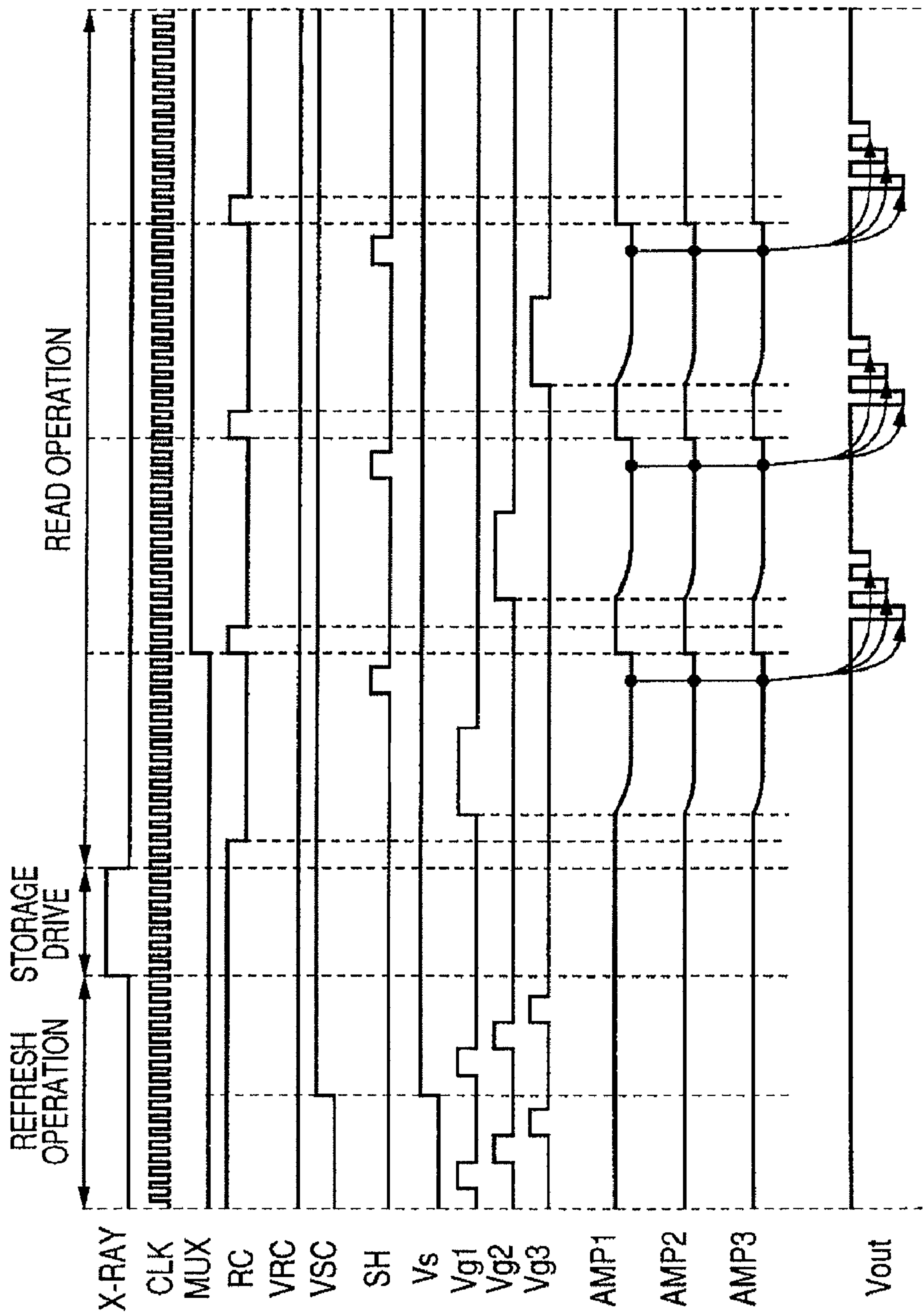


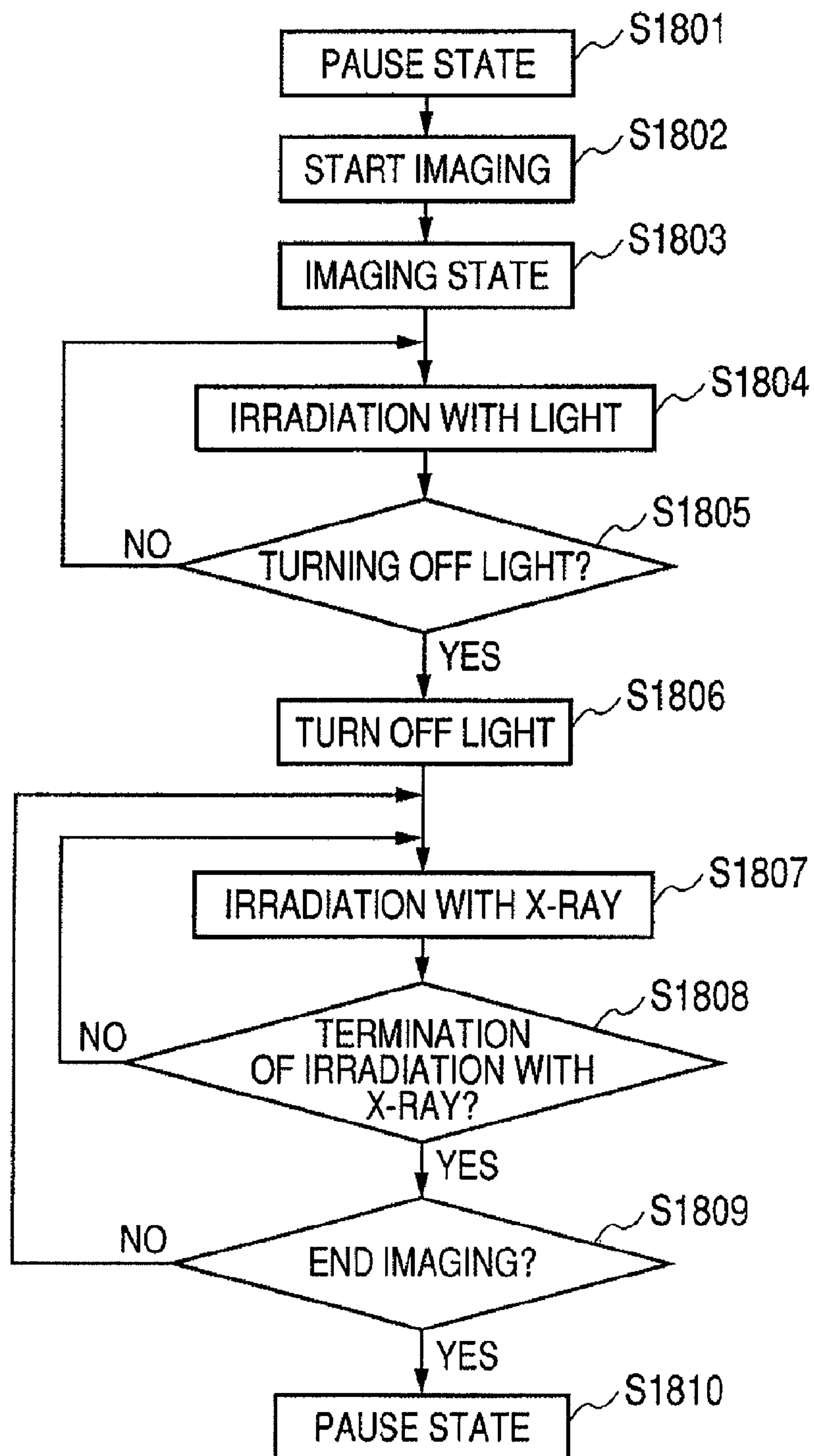
FIG. 10

FIG. 11

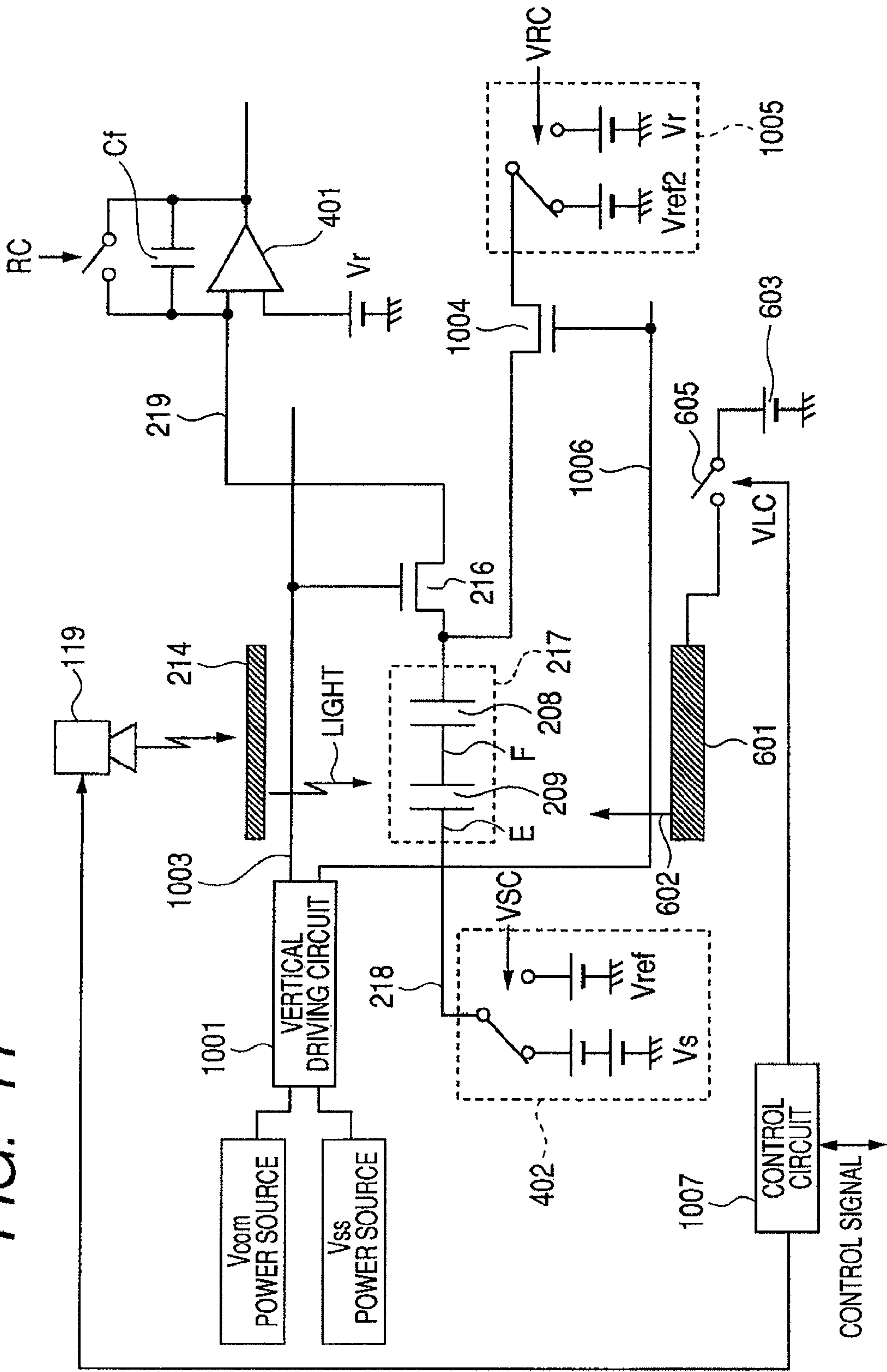


FIG. 12

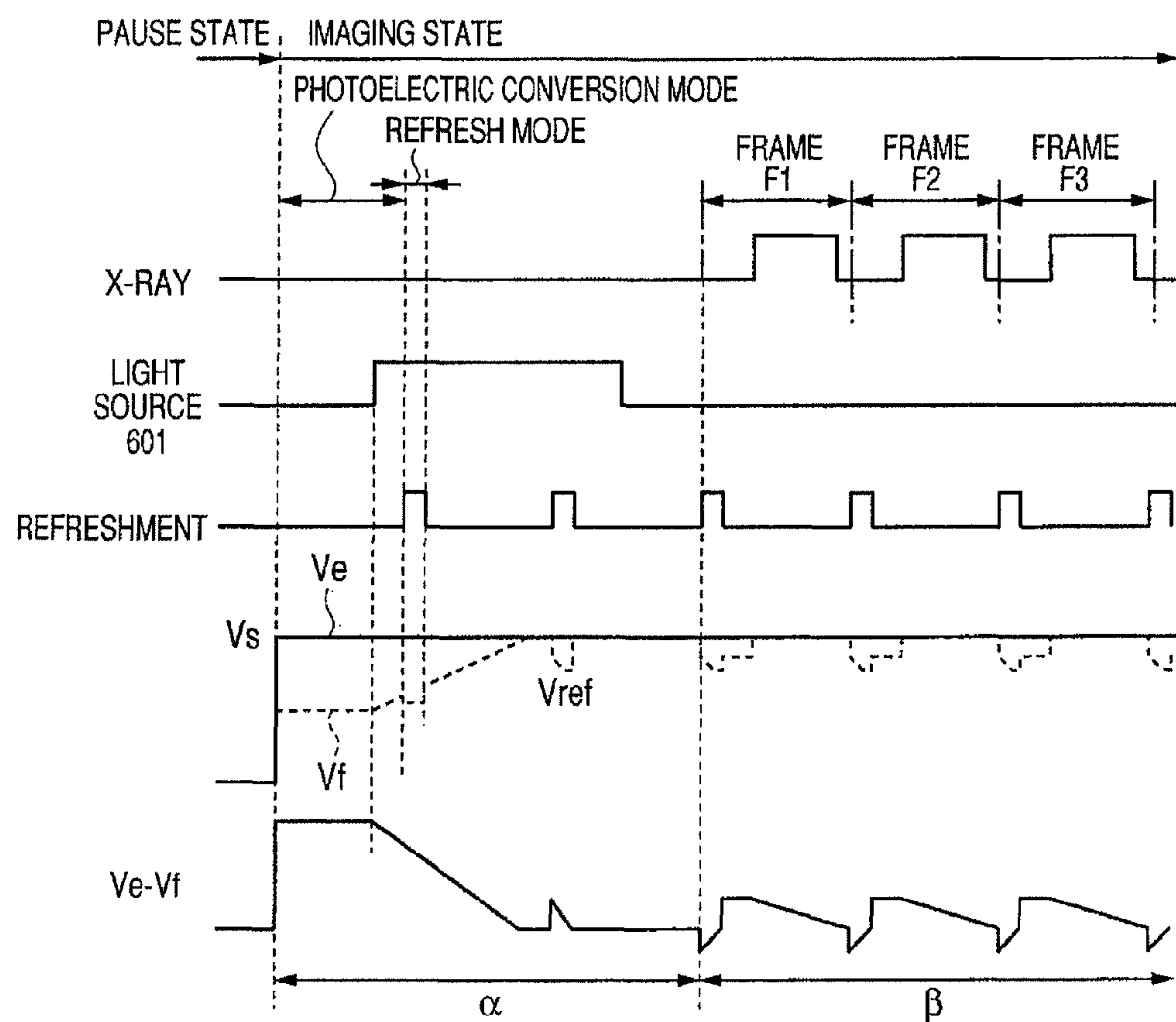


FIG. 13

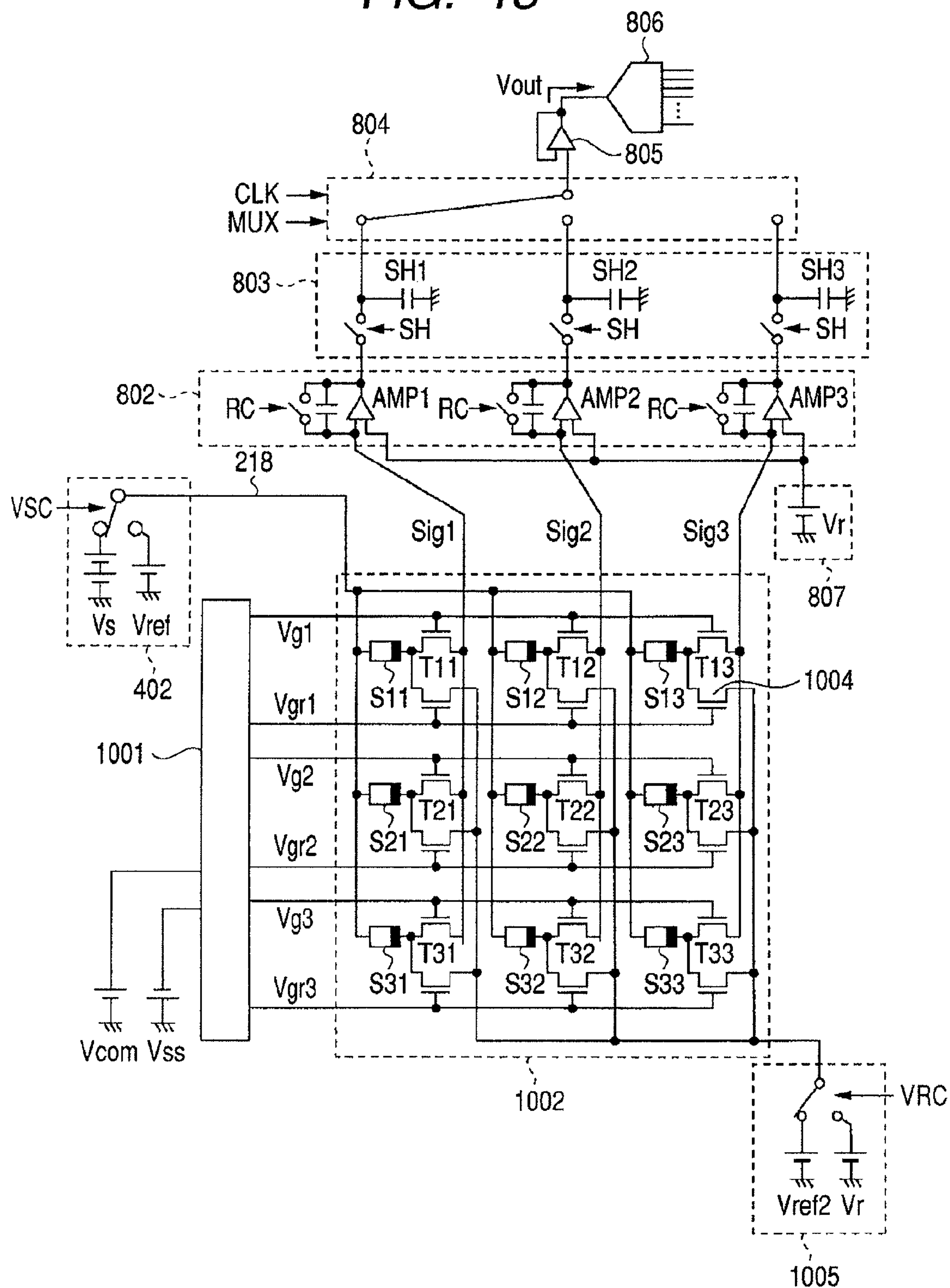


FIG. 14

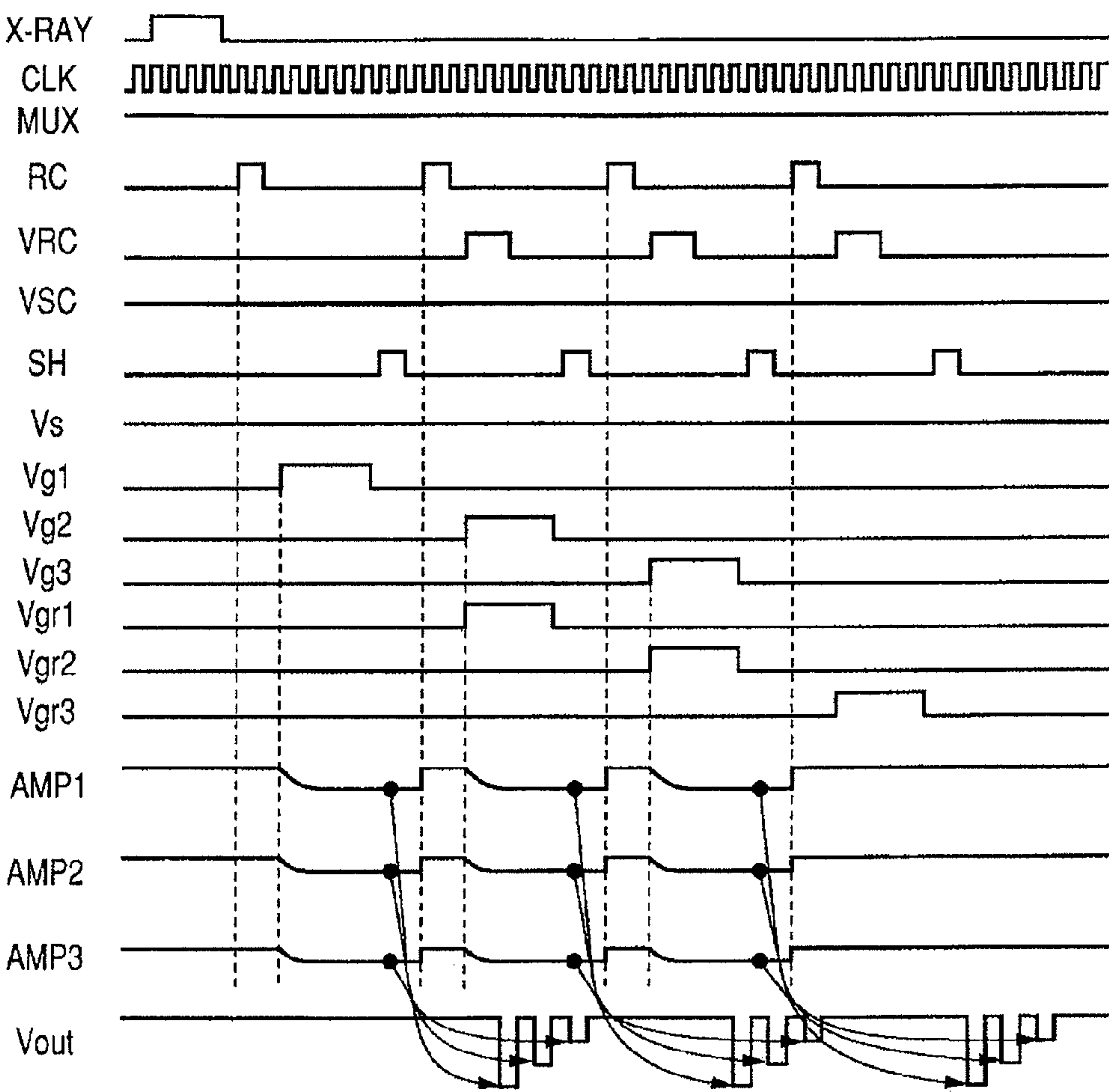


FIG. 15A

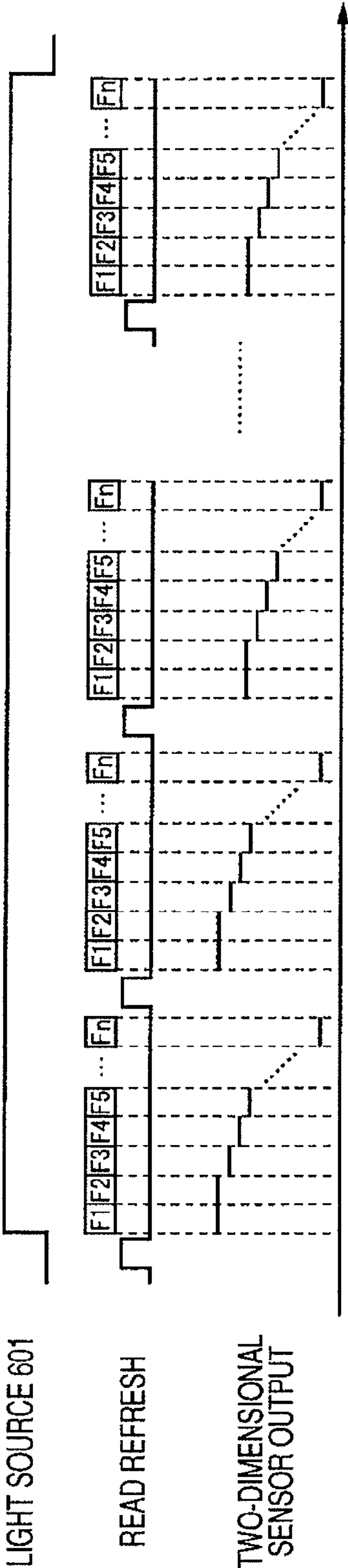


FIG. 15B

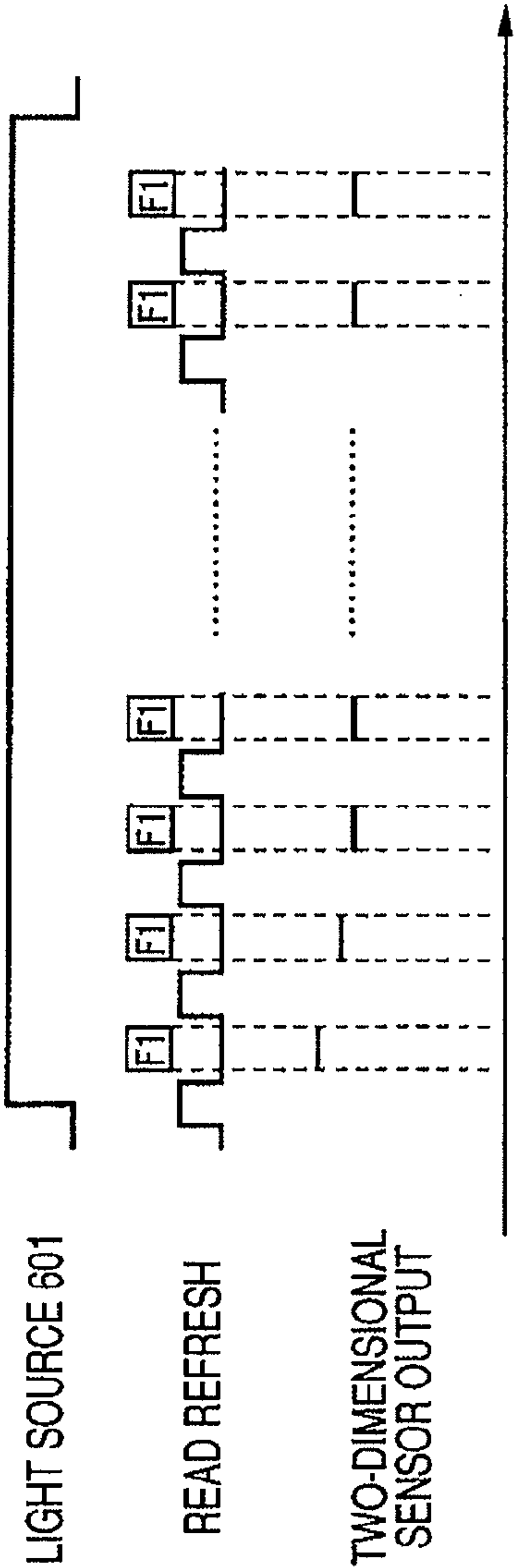


FIG. 15C

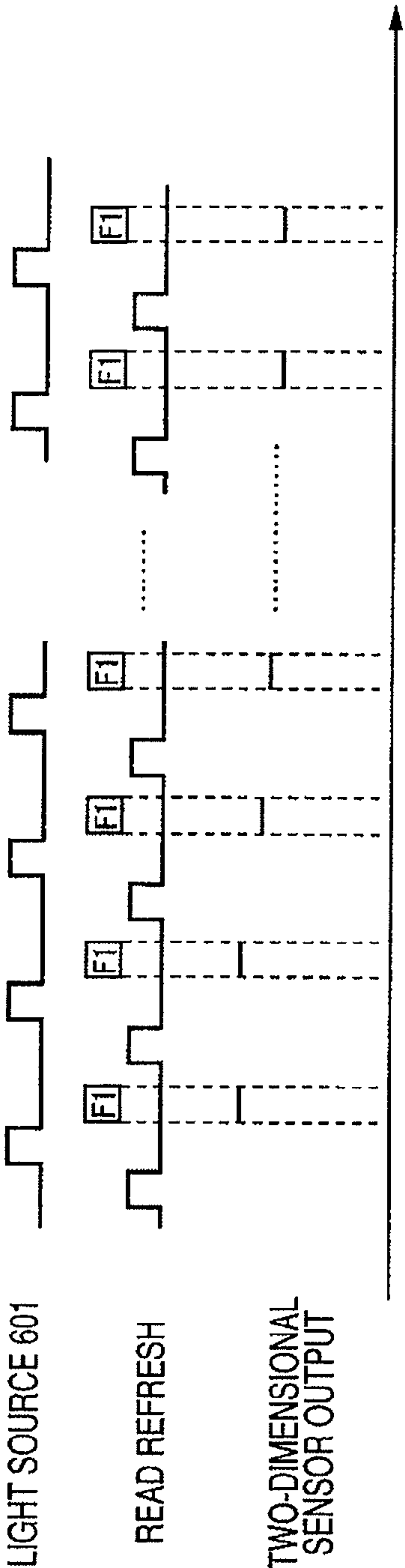


FIG. 15D

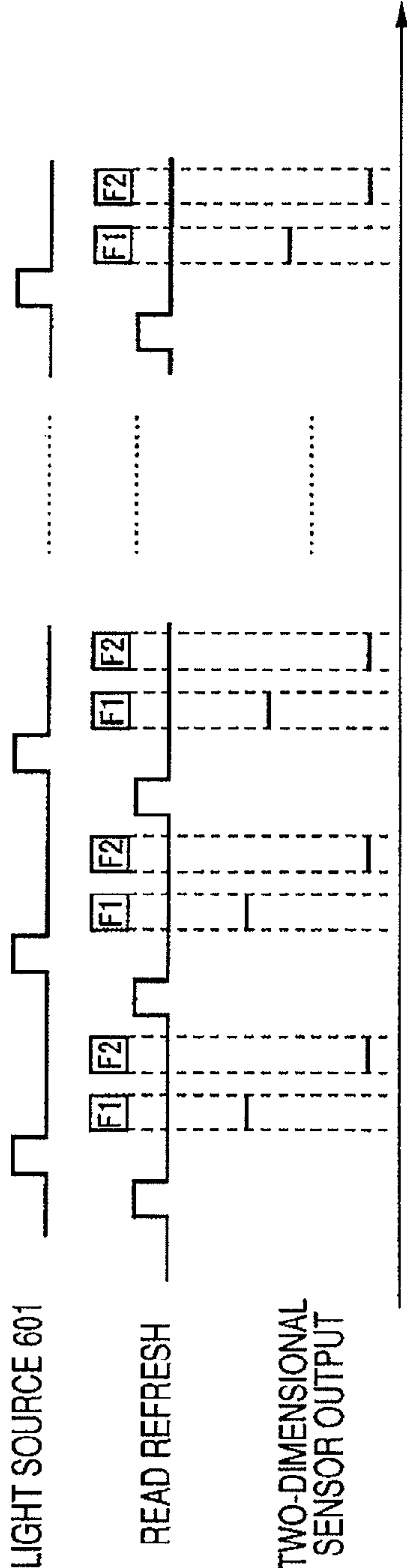


FIG. 16

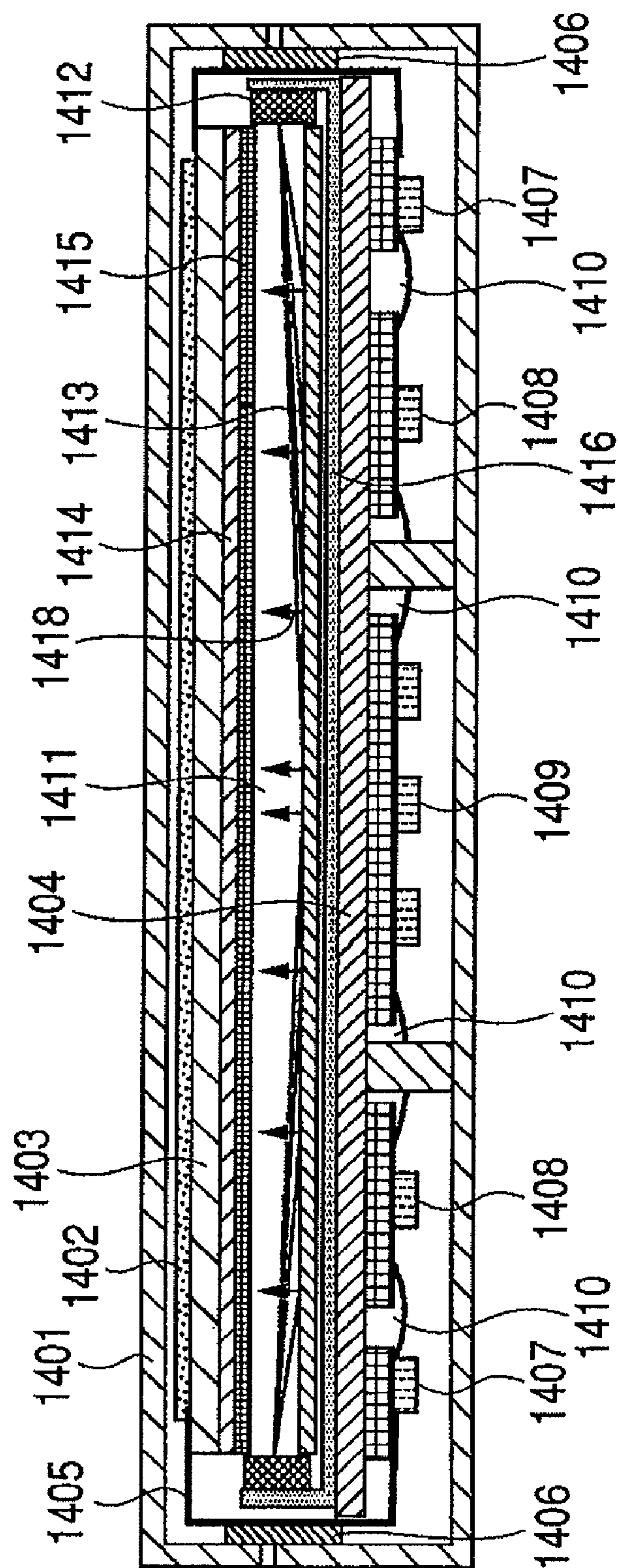


FIG. 17

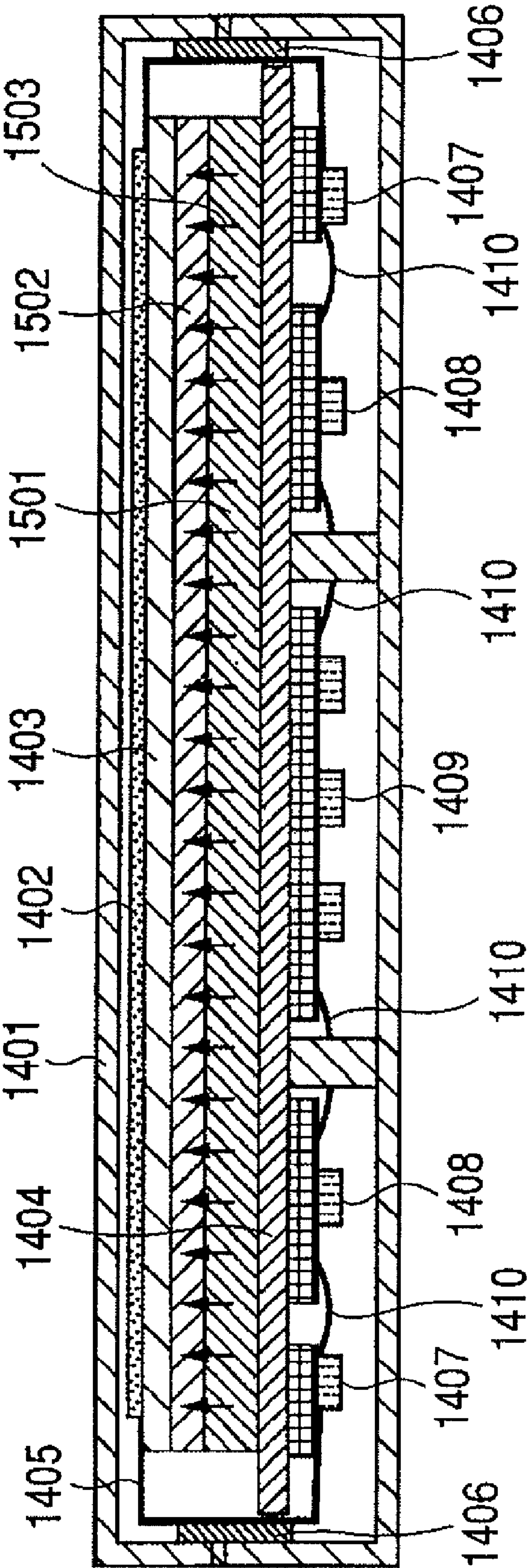


FIG. 18

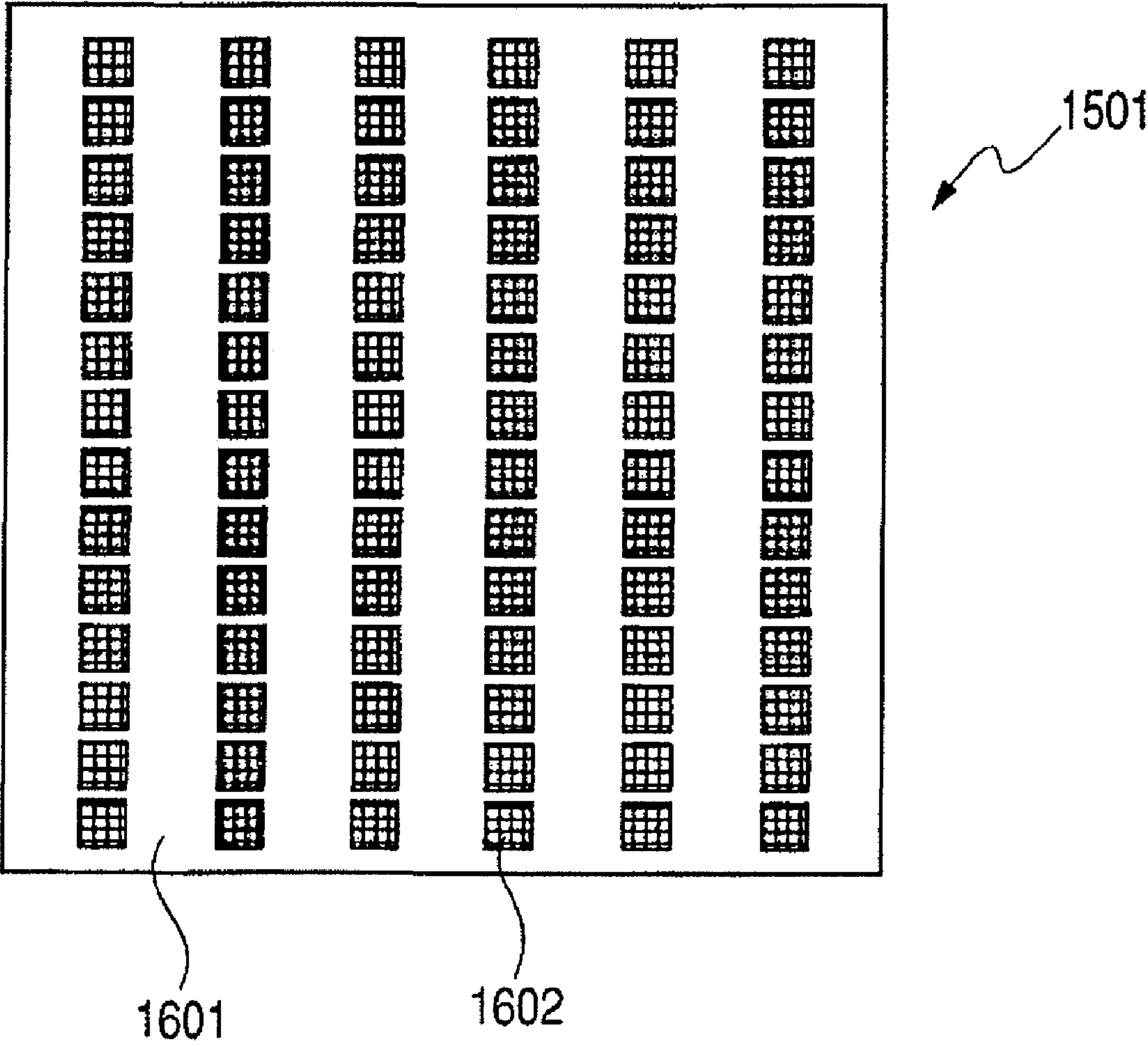
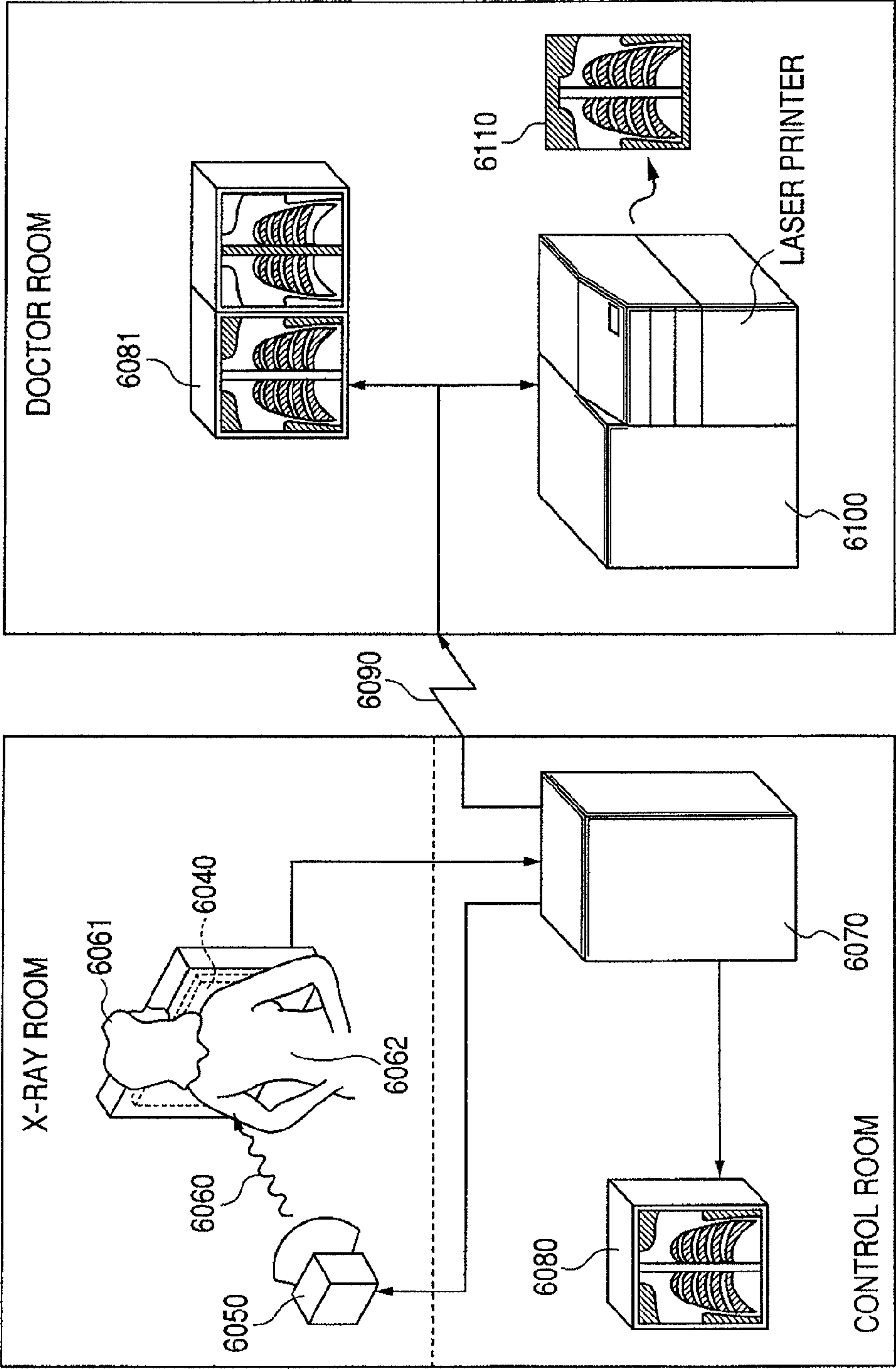


FIG. 19



RADIATION IMAGING APPARATUS, ITS CONTROL METHOD, AND RECORDING MEDIUM STORING PROGRAM FOR EXECUTING THE CONTROL METHOD

RELATED APPLICATIONS

The present application is a divisional of application Ser. No. 11/721,281, filed Jun. 8, 2007, which is a National Stage filing under 35 U.S.C. §371 of International Application No. PCT/JP2006/324121, filed Nov. 27, 2006. The present application claims benefit of parent application Ser. No. 11/721,281 (PCT/JP2006/324121) under 35 U.S.C. §120, and claims priority benefit under 35 U.S.C. §119 of Japanese Patent Applications 2006-305241, filed Nov. 10, 2006, and 2005-344537, filed Nov. 29, 2005. The entire contents of each of the mentioned prior applications are incorporated herein by reference.

TECHNICAL FIELD

The present invention relates to a radiation imaging apparatus to be preferably used for diagnosis for medical care and industrial non-destructive inspection and its control method. In the case of the present invention, it is assumed that electromagnetic waves such as X-rays and γ -rays, as well as particular beams of α -rays and β -rays, are included in the scope of the term "radiation".

BACKGROUND ART

In recent years, an X-ray digital imaging apparatus for performing imaging by using a converter such as a photoelectric transducer for converting light into an electrical signal and thereby using radiation such as X-rays is practically used and spread in accordance with the advancement of semiconductor technology.

Because a digital X-ray imaging apparatus has a sensitivity and image quality superior to those of a conventional film-type imaging apparatus, imaging at lower dose and improvement of diagnosability are possible. Moreover, because an image is stored as digital data, there are advantages that the image can be worked to an image which can be further diagnosed and the image can be easily controlled by performing various image processings after imaging the image. Moreover, by effectively using the advantage of digital data and thereby using a network to transfer image data, it is possible to make the image diagnosis in a hospital efficient and remote diagnosis efficient or realize new medical care service.

By using a digital X-ray imaging apparatus having these advantages, it is possible to provide medical care service higher than the case of a convention X-ray imaging apparatus in quality such as improvement of diagnostic accuracy, making diagnosis efficient, or development to new medical care service.

The above digital X-ray imaging apparatus is disclosed in U.S. Pat. No. 6,965,111, for example.

As a photoelectric conversion element used for the pixel of a two-dimensional area sensor of the X-ray imaging apparatus disclosed in U.S. Pat. No. 6,965,111, an MIS-type conversion element such as an MIS (Metal-Insulator-Semiconductor)-type photoelectric conversion element is mainly used and as a switching device, a TFT (Thin Film Transistor) is mainly used. The two-dimensional area sensor using the MIS-type photoelectric conversion element performs the

operation for initializing an MIS-type photoelectric conversion element referred to as the refresh operation disclosed in U.S. Pat. No. 6,075,256.

DISCLOSURE OF THE INVENTION

However, a state in which a refresh operation is not effective is present in an MIS-type photoelectric conversion element. Moreover, because the state is present, a change of sensitivities occurs. As a result, stable image quality is not obtained.

It is an object of the present invention to provide an imaging apparatus capable of restraining a change of image qualities due to a change of sensitivities of a photoelectric conversion element and its control method.

According to the present invention, it is possible to restrain the sensitivity change of a conversion element. Therefore, it is possible to restrain the fluctuation or image uncomfortable feeling of image luminance and obtain an image having a high image quality.

Further features of the present invention will become apparent from the following description of exemplary embodiments with reference to the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a sectional view showing the structure of a pixel using an MIS-type photoelectric conversion element;

FIG. 2A is an energy band diagram for explaining the photoelectric conversion mode of an MIS-type photoelectric conversion element, FIG. 2B is an energy band diagram for explaining the saturation state of an MIS-type photoelectric conversion element, and FIG. 2C is an energy band diagram for explaining the refresh mode of an MIS-type photoelectric conversion element;

FIG. 3 is a circuit diagram showing the configuration of one pixel of a two-dimensional sensor of an X-ray imaging apparatus;

FIG. 4 is a timing chart showing changes of potentials of points A and B in the pixel shown in FIG. 3;

FIG. 5 is a circuit diagram showing the configuration of one pixel of a two-dimensional sensor of the radiation imaging apparatus (X-ray imaging apparatus) of first embodiment of the present invention;

FIG. 6 is a timing chart showing changes of potentials of points C and D in the pixel shown in FIG. 5;

FIG. 7 is a circuit diagram showing the configuration of two-dimensional sensor in which nine pixels are arranged like a matrix;

FIG. 8 is an illustration showing the configuration of an X-ray imaging apparatus using the two-dimensional sensor shown in FIG. 7;

FIG. 9 is a timing chart showing operations of the two-dimensional sensor 801 of the first embodiment;

FIG. 10 is a flowchart showing the driving method of the two-dimensional sensor 801 of the first embodiment;

FIG. 11 is a circuit diagram showing the configuration of one pixel of a two-dimensional sensor of the radiation imaging apparatus (X-ray imaging apparatus) of second embodiment of the present invention;

FIG. 12 is a timing chart showing changes of potentials of points E and F in the pixel shown in FIG. 11;

FIG. 13 is a circuit diagram showing the configuration of a two-dimensional sensor in which nine pixels shown in FIG. 11 are arranged like a matrix and its peripheral circuits;

FIG. 14 is a timing chart showing operations of a two-dimensional sensor 1002 of the second embodiment;

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FIG. 15A is a timing chart showing an example of the relation between driving and output of a two-dimensional sensor when light is irradiated;

FIG. 15B is a timing chart showing another example of the relation between driving and output of a two-dimensional sensor when light is irradiated;

FIG. 15C is a timing chart showing another example of the relation between driving and output of a two-dimensional sensor when light is irradiated;

FIG. 15D is a timing chart showing still another example of the relation between driving and output of a two-dimensional sensor when light is irradiated;

FIG. 16 is an illustration showing an example of the embodiment of the X-ray imaging apparatus of an embodiment of the present invention;

FIG. 17 is an illustration showing another example of an embodiment of the X-ray imaging apparatus of the embodiment of the present invention;

FIG. 18 is an illustration showing an example of a surface-emission device; and

FIG. 19 is a schematic view showing the configuration of an X-ray imaging system.

BEST MODE FOR CARRYING OUT THE INVENTION

Hereafter, an embodiment of the present invention is specifically described by referring to the accompanying drawings.

First, the structure of a pixel using an MIS-type photoelectric conversion element is described by referring to FIG. 1. A TFT 216 is formed on a glass substrate 201. Moreover, a gate line 220, gate insulating film 202, channel layer 203, N+ amorphous silicon layer 204, drain electrode 205, and source electrode 206 are formed on the TFT 216. Furthermore, a signal line 219 for transferring an electrical signal output from the TFT 216 to a signal amplifying circuit is connected to the source electrode 206.

The MIS-type photoelectric conversion element 217 serving as an MIS-type conversion element is also formed on a glass substrate. Moreover, a sensor bottom electrode layer 207, insulating layer 208, photoelectric conversion layer 209, N+ amorphous silicon layer 210, transparent electrode 211, and sensor bias line 218 are formed on the MIS-type photoelectric conversion element 217. A voltage is supplied from the transparent electrode 211 and sensor bias line 218 to the photoelectric conversion layer 209. The N+ amorphous silicon layer 210 has an ohmic contact with the photoelectric conversion layer 209 and transparent electrode 211, which is a layer for blocking implantation of positive holes from the sensor bias line 218.

Moreover, a protective layer 212 for protecting the MIS-type photoelectric conversion element 217 and TFT 216 from humidity and foreign matter, phosphor 214 for converting radiation into light, adhesive layer 213 for adhering the phosphor 214 to the protective layer 212, and phosphor protective layer 215 are formed. The phosphor protective layer 215 protects the phosphor 214 from humidity or the like.

Then, the operational principle of the MIS-type photoelectric conversion element is described by referring to the energy band diagram of the MIS-type photoelectric conversion element shown in FIGS. 2A to 2C.

In the case of the photoelectric conversion mode shown in FIG. 2A, a positive voltage is applied to the sensor bias line 218 of the MIS-type photoelectric conversion element 217 and positive holes are accumulated. In the photoelectric conversion mode, when light 301 is irradiated to the photoelectric

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conversion layer 209, positive hole 303 and electron 302 are generated by the photoelectric effect in the photoelectric conversion layer 209. Then, the positive hole 303 is moved to the interface between the insulating layer 208 and photoelectric conversion layer 209 by an electric field and the electron 302 is moved to the N+ amorphous silicon layer 210 side. In this case, because the positive hole 303 cannot pass through the insulating layer 208, it is accumulated on the interface between the photoelectric conversion layer 209 and the insulating layer 208. When the positive hole 303 is accumulated, a voltage proportional to the dose of the light 301 or time is generated in the MIS-type photoelectric conversion element 217 and the potential of the bottom electrode layer 207 is lowered.

When the TFT 216 is turned on under the above state, current flows through the bottom electrode layer 207 and it is possible to obtain an image signal by detecting the current.

However, when a certain number of the positive holes 303 is accumulated, the saturation state shown in FIG. 2B is realized. That is, the voltage due to the positive holes 303 accumulated on the interface between the photoelectric conversion layer 209 and the insulating layer 208 becomes equal to the voltage applied to the MIS-type photoelectric conversion element 217 and an electric field is not generated in the photoelectric conversion layer 209. In this state, the positive hole 303 generated in the photoelectric conversion layer 209 cannot move up to the interface between the photoelectric conversion layer 209 and the insulating layer 208 and the positive hole 303 is recombined with the electron 302 and disappears. Therefore, a voltage proportional to the dose of the light 301 or time is not generated. Then, because a voltage proportional to the dose of the light 301 or time is not generated in the saturated MIS-type photoelectric conversion element 217, the sensitivity is lowered and a normal X-ray image cannot be obtained.

That is, the light sensitivity of the MIS-type photoelectric conversion element 217 depends on the voltage applied to the photoelectric conversion layer 209. The positive hole 303 generated by photoelectric effect is moved by an electric field applied to the photoelectric conversion layer 209 and reaches the interface between the photoelectric conversion layer 209 and the insulating layer 208. When this time is not shorter than the life time of the positive hole 303 decided by the film quality of the photoelectric conversion layer 209, the positive hole 303 cannot reach the interface between the photoelectric conversion layer 209 and the insulating layer 208, and it disappears.

Therefore, it is impossible to take the positive hole 303 out as an electrical signal. Therefore, to securely take out the positive hole 303 generated by photoelectric effect, it is necessary to increase the moving speed of the positive hole 303, that is, apply a sufficient voltage to the photoelectric conversion layer 209.

To return the MIS-type photoelectric conversion element 217 to the state of the photoelectric conversion mode shown in FIG. 2A again, it is necessary to set the voltage of the sensor bias line 218 to a voltage lower than that of the state in FIG. 2B and remove the positive hole 303 accumulated on the interface between the photoelectric conversion layer 209 and the insulating layer 208.

By performing the above operation, the refresh mode shown in FIG. 20 is realized and it is possible to newly accumulate positive holes 303 in the photoelectric conversion mode by the removed number of positive holes 303. Therefore, by setting the sensor bias to be supplied at the time of refresh operation to a lower value, it is possible that a sensor does not easily become a saturation state even if much light is

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irradiated. Moreover, it is possible to keep the voltage applied to the photoelectric conversion layer **209** constant by this refresh operation before light irradiation. Therefore, in the state in which the refresh operation is effective, sensitivities are not changed.

However, immediately after the refresh mode is changed to the photoelectric conversion mode, current due to electrons implanted into the MIS-type photoelectric conversion element **217** in the refresh mode flows. Therefore, dark current is temporarily increased. Moreover, the number of electrons implanted into the photoelectric conversion layer **209** is increased as the sensor bias at the time of refresh is towered. Therefore, sensor biases in the refresh mode and photoelectric conversion mode are selected in view of the dynamic range desired for a digital X-ray imaging apparatus and dark current.

Then, in the case of the above MIS-type photoelectric conversion element, a state in which the refresh operation is not effective is described below. FIG. **3** is a circuit diagram showing the configuration of one pixel of the two-dimensional sensor (sensor unit) in an X-ray imaging apparatus.

As described above, one pixel includes the TFT **216** and MIS-type photoelectric conversion element **217**. Moreover, the gate line **220** is connected to the gate of the TFT **216** and the signal line **219** is connected to the source electrode **206** of the TFT **216**. Moreover, the sensor bias line **218** for applying a voltage required to perform photoelectric conversion and refresh is connected to the MIS-type photoelectric conversion element **217**. The signal line **219**, gate line **220**, and sensor bias line **218** are shared by a plurality of pixels constituting a two-dimensional sensor.

The gate line **220** is connected to a vertical driving circuit **105** and a voltage for selectively turning on/off the TFT **216** is supplied from the vertical driving circuit **105**. The sensor bias line **218** is connected to a sensor power supply **402**. The sensor power supply **402** includes a power supply V_s for photoelectric conversion and a power supply V_{ref} necessary for the refresh of a sensor, in which power supply outputs can be optionally changed by a control signal VSC. The signal line **219** connects the source electrode **206** of the TFT **216** and the input of a signal amplifying circuit constituted by using a current-integrating-type amplifier **401**. The amplifier **401** converts a current signal corresponding to electric charges transferred from the TFT **216** accumulated in the MIS-type photoelectric conversion element **217** into a voltage signal and amplifies the signal. The current input to the amplifier **401** is accumulated in an integrating capacitor C_f to output voltages proportional to voltages generated at the both ends of the integrating capacitor C_f .

When reading the electric charges accumulated in the MIS-type photoelectric conversion element **217**, it is necessary to reset electric charges accumulated at the time of latest read or electric charges accumulated by the offset current of the amplifier **401**. The integrating capacitor C_f is reset by turning on a switch SW following the integrating capacitor C_f in accordance with a control signal RC.

FIG. **4** is a timing chart showing changes of voltages of points A and B in the pixel shown in FIG. **3**. FIG. **3** shows a voltage ($V_a - V_b$) applied to the photoelectric conversion layer **209** together with potential V_a of the point A and potential V_b of the point B when repeating irradiation with X-ray and refresh from immediately after turning-on of a power supply. In the following description, operations of the TFT **216** are omitted. However, the TFT **216** is driven synchronously with refresh or read. Moreover, when a power supply is turned on, it is assumed that the TFT **216** is regularly turned on/off.

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To change the operation halt state to the imaging possible state, supply of voltages is started from the sensor power supply **402**, power supply V_{com} , and power supply V_{ss} . In this case, the potential V_a becomes equal to the voltage V_s . However, the potential V_b is shown by the following Numerical Formula 1 when assuming the capacitance of the photoelectric conversion layer **209** as C_i , the capacitance of the insulating layer **208** as C_{SiN} , and the reference power supply of the amplifier **401** as V_r :

$$V_b = \frac{C_i}{C_i + C_{SiN}} \times (V_s - V_r) + V_r \quad (\text{Numerical Formula 1})$$

The potential V_b rises due to accumulation of generated electric charges because when X-ray is irradiated, the photoelectric effect occurs by the light of a phosphor for emitting light by receiving X-ray. Moreover, in the refresh mode (state in which the voltage V_{ref} is supplied to the sensor bias line **218**), because the voltage V_a is changed from V_s to V_{ref} , the voltage V_a lowers by a voltage ΔV shown by the following Numerical Formula 2:

$$\Delta V = \frac{C_i}{C_i + C_{SiN}} \times (V_s - V_{ref}) \quad (\text{Numerical Formula 2})$$

In period α of $V_v < V_{ref}$, because the band of the MIS-type photoelectric conversion element **217** has the same band structure as in the case of photoelectric conversion mode, the MIS-type photoelectric conversion element **217** is not refreshed.

Thereafter, while irradiation of X-ray is repeated, electric charges are accumulated on the interface between the photoelectric conversion layer **209** and the insulating layer **208** and the potential V_b rises. Then, in period β , in which V_b becomes equal to or larger than V_{ref} at the time of refresh, refresh shows an effect. That is, the effect of refresh is first shown by making the state of the MIS-type photoelectric conversion element **217** approach to the saturation state.

Thus, in period α , the voltage ($V_a - V_b$) applied to the photoelectric conversion layer **209** is slowly lowered because electric charges generated by photoelectric effect are accumulated. Therefore, in period α , the sensitivity of the MIS-type photoelectric conversion element **217** is slowly lowered whenever imaging is performed. Then, when imaging a plurality of sheets in the period α , a problem occurs that the contrast of an image is slowly lowered due to a change of sensitivities whenever imaging is performed or a problem occurs that sensitivities are changed between a sensor receiving a large dose of light and a sensor receiving a smaller dose of light, and a problem occurs in that the image produced in the last imaging contains a feature that produces an uncomfortable feeling in the viewer. Moreover, when continuously imaging images, as in the case of a dynamic image, the luminance of the whole image is slowly lowered from the start of imaging. As a result, when such a feature (producing the mentioned uncomfortable feeling) occurs in an X-ray imaging apparatus used for diagnosis or operation, the diagnostic performance A is lowered, or erroneous diagnosis may occur, and the mentioned uncomfortable feeling may interfere with the activity of the user in a case in which a see-through image is used.

However, in period β , it is possible to keep the potential V_b before irradiation of X-ray constant because refresh is effective. That is, it is possible to keep the voltage applied to the

photoelectric conversion layer **209** constant by the refresh performed immediately before imaging and stabilize the sensitivity.

To decrease the period α in which sensitivity is fluctuated, a method for lowering the voltage V_{ref} is used. By lowering the voltage V_{ref} , the refresh quantity is increased and refresh is effective even when a small number of electric charges are accumulated. Therefore, it is possible to shorten the period α .

However, when lowering the voltage V_{ref} , implantation quantity of electrons from the sensor bias line **218** to the photoelectric conversion layer **209** is increased in the refresh mode. Therefore, it is known that the dark current after refresh is increased or fluctuation of dark current characteristic every pixel is increased. Therefore, it is not a preferable method to lower the voltage V_{ref} .

Moreover, a method for continuously applying a voltage to a pixel to keep period β is considered. However, when always applying a voltage to the MIS-type photoelectric conversion element **217**, deterioration of the characteristic is accelerated. Therefore, this is not preferable in view of the reliability of the apparatus. Actually, a conventional digital X-ray imaging apparatus restrains characteristic deterioration of the two-dimensional sensor **103** by stopping voltage supply to the sensor bias source **218**, power supply V_{com} , and power supply V_{ss} when imaging is not performed and supplying no voltage to the two-dimensional sensor **103**.

Thus, in the case of a digital X-ray imaging apparatus using a two-dimensional area sensor (sensor unit) having an MIS-type conversion element, it is difficult to restrain lowering of sensitivity by control or adjustment of a voltage to be applied to a two-dimensional sensor. The present inventors have found the above problem.

As a result of earnestly repeating study in order to solve the above problem in view of the above situation, the present inventors have reached the following various modes of the invention.

First Embodiment

First, first embodiment of the present invention is described below. FIG. **5** is a circuit diagram showing the configuration of one pixel of a two-dimensional sensor (sensor unit) in a radiation imaging apparatus (X-ray imaging apparatus) of the first embodiment of the present invention. In FIG. **5**, a component provided with the same symbol as that in FIG. **1**, **3** or the like is a device or circuit having the same function and its description is omitted.

This embodiment is provided with a light source **601**, power supply **603** for making the light source **601** emit light, and switch **605** as means for bringing the MIS-type photoelectric conversion element **217** into a saturation state before performing X-ray imaging. As the light source **601**, it is possible to use a light source capable of discharging the light having a wavelength which can be detected by the photoelectric conversion layer **209** serving as the conversion layer of an MIS-type conversion element at optional timing. For example, when an MIS-type photoelectric conversion element using amorphous silicon is used as an MIS-type conversion element, it is possible to use a device in which a plurality of LEDs or cold-cathode tubes are arranged, a device in which a light guide plate and a LED or cold-cathode tube are combined, or EL device. It is to be noted that the light having a wavelength which can be detected by the MIS-type photoelectric conversion element may include also a radiation such as infrared rays and ultraviolet rays or the like other than the visible light.

Moreover, a control circuit **604** for controlling the light source **601** and an X-ray source **119** is provided. That is, the control circuit **604** can control light emission/no light emission of the light source **601** or control exposure of X-ray from the X-ray source **119**. For example, light irradiation by the light source **601** is controlled by the control circuit **604** so that the light is irradiated only for predetermined necessary time. In this case, it is preferable that the control circuit **604** sets the control circuit **604** so that it cannot expose the X-ray source **119** and X-ray is not erroneously irradiated.

Then, operations of one pixel constituted as described are described by referring to FIG. **6**. FIG. **6** is a timing chart showing changes of voltages of points C and D in the pixel shown in FIG. **5**. FIG. **6** shows a voltage ($V_c - V_d$) applied to the photoelectric conversion layer **209** together with the potential V_c of the point C and the potential V_d of the point D when repeating X-ray irradiation and refresh from immediately after turning-on of a power supply.

First, the pause state in which no voltage is supplied to a two-dimensional sensor is changed to the imaging state for supplying a voltage to the MIS-type photoelectric conversion element **217** and TFT **216**. In this state, as described above, the potential of the sensor bias line **218** becomes V_s and the voltage applied to the MIS-type photoelectric conversion element **217** is shown by Numerical Formula 1.

Under this state, light is irradiated from the light source **601** to the MIS-type photoelectric conversion element **217**. As a result, electric charges are generated in the photoelectric conversion layer **209** and the voltage applied to the photoelectric conversion layer **209** is lowered.

Irradiation of light from the light source **601** in this case is performed until the MIS-type photoelectric conversion element **217** completely reaches a saturation state. Thereby, a constant voltage is always applied to the photoelectric conversion layer **209** by refresh operation and it is possible to restrain a change of sensitivities every imaging.

Then, when the MIS-type photoelectric conversion element **217** is saturated, light irradiation from the light source **601** is stopped and X-ray imaging is started.

It is preferable to adjust the quantity of light radiated from the light source **601** in view of the voltages V_s and V_{ref} , capacitance of photoelectric conversion layer **209** and the insulating layer **208**, and utilization efficiency of light. Moreover, in the case of driving of a pixel, it is allowed to repeat refresh operation, accumulating operation, and read operation or repeat only the read operation. Moreover, at least one-time refresh operation is necessary from the time when light irradiation from the light source **601** is completed up to X-ray imaging. This is because a photoelectric conversion element is saturated when light irradiation by the light source **601** is completed, a sufficient image cannot be obtained when directly performing X-ray imaging.

Moreover, it is allowed to continue imaging interval as shown in FIG. **6** or not to continue the imaging interval. That is, as shown in FIG. **16C** or **16D** to be described later, when irradiating light in order to previously saturate a photoelectric conversion element, it is allowed to irradiate light intermittently (like pulse). Furthermore, it is allowed to perform imaging not irradiating X-rays between X-ray images and correct an X-ray image imaged immediately before by using the image.

Moreover, after irradiation of sufficient light by the light source **601** is completed by a control signal of the control circuit **604**, it is preferable to change a display for communicating that a worker may be exposed to X-rays. Furthermore, when operations of a two-dimensional sensor are different before start of X-ray imaging and after start of X-ray imaging,

it is allowed to change driving of the sensor in accordance with a signal of the control circuit **604**.

It is allowed that the control circuit **604** is provided for a control computer **108** or program/control board **110** of a conventional X-ray imaging apparatus. Moreover, it is allowed to realize the function of the control circuit **604** by combining operations of the control computer **108** and program/control board **110**.

Then, a two-dimensional sensor (sensor unit) having 9 above pixels (3×3 pixels) and its peripheral circuits are described below. FIG. 7 is a circuit diagram showing the configuration of a two-dimensional sensor in which nine pixels shown in FIG. 5 are arranged like a matrix and its peripheral circuits. Moreover, FIG. 8 is an illustration showing the configuration of an X-ray imaging apparatus using the two-dimensional sensor shown in FIG. 7.

The two-dimensional sensor (sensor unit) **801** shown in FIG. 7 is constituted when the MIS-type photoelectric conversion element **217** (S11-533) and thin-film transistor (TFT) **216** (T11-T33) are arranged like a matrix of 3×3. The MIS-type photoelectric conversion element **217** (S11-S33) converts light emitted from a phosphor into an electrical signal. The thin-film transistor **216** (T11-T33) outputs electric charges accumulated in the MIS-type photoelectric conversion element **217** at optional timing. Though not shown in FIG. 7, a phosphor **101** is provided on the MIS-type photoelectric conversion element **217** as shown in FIG. 8. The phosphor **101** mainly contains Gd₂O₂S, Gd₂O₃ and/or CsI: Tl.

The two-dimensional sensor **801** has amplifiers AMP1 to AMP3 respectively provided with a capacitance Cf for accumulating electric charges output from the TFT **216** and connects with a signal amplifying circuit **802** for amplifying a signal. Signal lines Sig1 to Sig3 are set between the signal amplifying circuit **802** and the two-dimensional sensor **801**. The signal lines Sig1 to Sig3 are connected to the drain electrode of the TFT **216**. The signal amplifying circuit **802** connects with an Amp reference power supply **807** serving as the reference power supply of the amplifiers AMP1 to AMP3. Moreover, the signal amplifying circuit **802** connects with a sample-and-hold circuit **803** for holding output voltage of the signal amplifying circuit **802** for an optional period and multiplexer **804** for serially outputting signals held by the sample-and-hold circuit **803**. The sample-and-hold circuit **803** holds an electrical signal output from the signal amplifying circuit **802** until the circuit **802** is selected by the multiplexer **804**. Moreover, the signal amplifying circuit **802** connects with a buffer amplifier **805** for outputting the output of the multiplexer **804** at a low impedance and A/D converter **806** for converting an analog signal into a digital signal. The signal amplifying circuit **802**, sample-and-hold circuit **803**, multiplexer **804**, and buffer amplifier **805** are included in a signal processing circuit **809**.

Moreover, the two-dimensional sensor **801** connects with a power supply Vs necessary for photoelectric conversion and sensor power supply **402** provided with the power supply Vref for setting the MIS-type photoelectric conversion element **217** to a refresh mode. The sensor bias line **218** is connected between the N+ amorphous silicon layer of the MIS-type photoelectric conversion element **217** and the sensor power supply **402**. The sensor power supply **402** and Amp reference power supply **807** are included in a low-noise power supply **827**.

Moreover, a vertical driving circuit **105** for driving gate lines Vg1 to Vg3 connected to the gate electrode of the TFT **216** of the two-dimensional sensor **801** is provided. The vertical driving circuit **105** connects with the power supply

Vcom for turning on the TFT **216** and power supply Vss for turning off the TFT **216**. The vertical driving circuit **105** sequentially supplies a voltage pulse constituted of voltages Vcom and Vss to three gate lines Vg1 to Vg3 by optional time.

Signal lines Sig1 to Sig3 and sensor bias line **218** are shared by top and bottom pixels and gate lines Vg1 to Vg3 are shared by right and left pixels. Moreover, it is assumed that the control circuit **604** in FIG. 6 is included in the control computer **808**.

A control panel **124**, the phosphor **101**, a two-dimensional sensor (sensor unit) **103**, and the light source **601** are arranged within an envelope **112** of a flat panel detector.

Then, driving methods and operations of the two-dimensional sensor **801** constituted as described above and its peripheral circuits are described by referring to FIGS. 10 and 11. FIG. 9 is a timing chart showing operations of the two-dimensional sensor **801** of the first embodiment and FIG. 10 is a flowchart showing the driving method of the two-dimensional sensor **801** of the first embodiment.

Before imaging is started, an X-ray imaging apparatus is kept in a pause state (step S1801). In this case, the pause state represents a state in which no voltage is applied to the MIS-type photoelectric conversion element **217** and TFT **216** in the two-dimensional sensor **801**. By keeping this state, it is possible to keep service lives of the TFT **216** and MIS-type photoelectric conversion element **217** which are easily deteriorated due to long-time application of voltage long. Moreover, in the pause state, it is preferable to cut off supply of power to the signal processing circuit **809** such as the signal amplifying circuit **802** except a necessary portion to save power.

Then, when an operator starts imaging by performing a necessary procedure (step S1802), a predetermined voltage is applied to the two-dimensional sensor **801**, the voltage Vs is applied to the MIS-type photoelectric conversion element **217** and the voltage Vss is applied to the gate lines Vg1 to Vg3. Moreover, a voltage necessary for the Amp reference power supply and driving is also applied to the signal amplifying circuit **802** and an operation state is started (step S1803).

After starting the imaging state, light is irradiated from the light source **601** under control of control circuit **604** (control computer **808**) (step S1804). The output of the two-dimensional sensor **801** is sent to the control computer **808** after the output is converted into digital data and necessary processing is applied. The control circuit **604** determines whether to realize a saturation state or stop irradiation of light in accordance with the data (step S1805). However, while light is being irradiated, as shown in FIG. 6, refresh operation, photoelectric conversion operation, and read are repeated.

For control of irradiation and stop of light, it is allowed to stop irradiation after performing the irradiation only by a preset time, for example. In this case, the time for irradiating light can be programmed in the control computer **808**. Then, it is allowed to set the irradiation time when the two-dimensional sensor **801** is fabricated or at the time of setting after fabrication. Moreover, it is allowed to monitor the output fluctuation from the MIS-type photoelectric conversion element **217** at the time of light irradiation and determine light irradiation stop time.

Then, when the control computer **808** determines stopping of irradiation of light, it stops irradiation in step S1806.

Then, the two-dimensional sensor **801** also starts the operation for imaging by an operator when X-ray irradiation is started (step S1807).

In this case, the operation for imaging a static image is described below. Moreover, as shown in FIG. 9, it is assumed

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to obtain a static image by three operations of refresh operation, accumulation operation, and read operation of the MIS-type photoelectric conversion element **217**.

To obtain a static image, the MIS-type photoelectric conversion element **217** is first refreshed by using the sensor power supply **402**. In this case, the MIS-type photoelectric conversion element **217** is refreshed by using the sensor power supply **402** in order to secure a large dynamic range necessary for a static image.

In this refresh operation, the control signal VSC is first set to low (Lc) to supply the voltage Vref optimum for refresh to the sensor bias line **218**. However, in this case, because the potential of the sensor bias line **218** side of MIS-type photoelectric conversion element **217** and the potential of a sensor bottom electrode layer **207** simultaneously rise, the refresh mode is not realized.

To realize the refresh mode, the voltage Vcom is further supplied to the gate lines Vg1 to Vg3 by the vertical driving circuit **105** to turn on the TFT **216** and equalize the potential of the sensor bottom electrode layer **207** with potentials of the signal lines Sig1 to Sig3. In this case, the control signal RC of the amplifiers AMP1 to AMP3 is set to high (Hi) to set potentials of the signal lines Sig1 to Sig3 to the reference potential Vr.

In the case of the timing chart shown in FIG. 9, the TFT **216** for each pixel is turned on for each line. However, it is also allowed to simultaneously turn on all TFTs **216**.

Then, after setting all pixels to the refresh mode, the voltage Vs suitable for the photoelectric conversion mode is output to the two-dimensional sensor **801** by turning off the TFTs **216** and setting the control signal VSC of the sensor power supply **402** high (Hi).

In this case, the MIS-type photoelectric conversion element **217** is not changed to the photoelectric conversion mode only by changing the voltage applied to the sensor bias line **218** like the case of refresh operation. Therefore, the TFTs **216** are turned on by the vertical driving circuit **105**. The refresh operation is completed by setting all pixels to the photoelectric conversion mode.

After completing the refresh operation, accumulation operation is started. When the two-dimensional sensor **801** starts the accumulation operation, it is communicated to an operator that X-ray can be exposed. This information can be performed through, for example, a control console **113**, operation indicator lamp **125**, or monitor **118**.

Then, when an X-ray exposure switch set to an X-ray control console **115** is pushed by an operator, exposure of the subject to X-rays is started by the X-ray power supply **119** and X-rays are irradiated for a necessary time in accordance with the portion to be imaged or dosed. The program/control board **110** controls the dose and completes irradiation of X-rays at the stage of a proper dose (step S1808).

The read operation for transferring electric charges having the information on human bodies accumulated in the MIS-type photoelectric conversion element **217** is started simultaneously with completion of X-ray imaging. The read operation is constituted of two operations such as the reset operation which is a preparing operation for transferring electric charges accumulated in the MIS-type photoelectric conversion element **217** and the signal transferring operation for transferring electric charges accumulated in the MIS-type photoelectric conversion element **217** to the signal amplifying circuit **802**.

First, the control signal RC is set to high (Hi) to reset all capacitances Cf of the signal amplifying circuit **802**. By setting the signal amplifying circuit **802** and signal lines Sig1 to Sig3 to a state suited to transfer a signal by the reset operation,

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it is prevented that a signal not related to the information on human bodies to be accumulated in the capacitance Cf at the time of accumulating operation is read. Moreover, though potentials of the signal lines Sig1 to Sig3 are unstable due to the influence of potential fluctuations of the gate lines Vg1 to Vg3, the potentials are reset to the reference voltage Vrf of the Amp reference power supply **807** and stabilized by the reset operation. Then, after performing resetting for sufficient time, the control signal RC is set to low (Lo) to complete resetting.

Then, the signal transferring operation is performed. In the case of the signal transferring operation for transferring electric charges accumulated in the MIS-type photoelectric conversion element **217**, voltages of the gate lines Vg1 to Vg3 are sequentially changed from the voltage Vss to voltage Vcom by the vertical driving circuit **105** to turn on the TFT **216**. When the TFT is turned on, electric charges accumulated in the MIS-type photoelectric conversion element **217** are transferred to capacitances Of the signal amplifying circuit **802**. For example, when the voltage of the gate line Vg1 becomes the voltage Vcom, TFT T11 to TFT T13 are turned on and electric charges accumulated in the MIS-type photoelectric conversion elements S11 to S13 are transferred to amplifiers AMP1 to AMP3.

Then, after turning on the TFT **216** until electric charges are sufficiently transferred, the voltage to be applied to the gate lines Vg1 to Vg3 is changed to the voltage Vss to turn off the TFT **216** and complete transfer of signals. It is only necessary to set the time for keeping the TFT **216** turned-on by considering the capacitance of the MIS-type photoelectric conversion element **217**, the ON characteristic of the TFT **216** and the voltage Vcom.

After transferring signals to the signal amplifying circuit **802**, the control signal SH of the sample-and-hold circuit **803** is set to high (Hi) to transfer outputs of the amplifiers Amp1 to Amp3 connected to sample-and-hold capacitances SH1 to SH3 to sample-and-hold capacitances SH1 to SH3. The control signal SH is kept high (Hi) until voltages output from the amplifiers Amp1 to Amp3 are sufficiently transferred to sample-and-hold capacitances and after transfer is completed, the voltages are set to low (Lo).

Electrical signals transferred to the sample-and-hold capacitances SH1 to SH3 are read by the multiplexer **804** in time series during the signal transferring period of the next line (lower line) as shown in FIG. 10.

By applying these transferring operations to all lines, it is possible to transfer electrical signals accumulated in all pixels.

After transferring the electrical signals, operation is changed in accordance with whether to complete imaging (step S1809). When completing imaging (a case in which X-ray irradiation is not performed for long time is also included), the two-dimensional sensor **801** is brought to pause state in order to prevent characteristic deterioration of the MIS-type photoelectric conversion element **217** and TFT **216** (step S1809). When moving to the pause state, irradiation of light by the light source **601** is necessary before X-ray irradiation by all means.

However, when X-ray irradiation is resumed, a state in which X-ray irradiation is possible is directly realized because a state in which the refresh operation is effective is maintained (step S1807).

Thus, it is enough to perform irradiation of light only when the two-dimensional sensor **801** is changed from the pause state to the imaging state but it is not necessary to perform irradiation of light whenever X-ray irradiation is performed. Moreover, it is allowed to change whether to move to a pause

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state after completion of irradiation with X-rays or transfer of electric charges to judgment of an operator or make a program so that when the time previously set by a timer elapses, the pause state is started. Furthermore, it is preferable to display whether the two-dimensional sensor **801** is set to the pause state or imaging state on the monitor **118** so that an operator can always confirm the state.

According to this operation, it is possible to stably acquire a static image having a preferable image quality without lowering sensitivity.

It is preferable that the operation timing and voltage of the above embodiment use proper values in accordance with the withstand voltage or characteristic of the TFT **216** and MIS-type photoelectric conversion element **217**. Moreover, it is allowed to perform the read operation so that the multiplexer **804** is not operated after refresh operation. By performing this operation, it is possible to exclude a dark current generated immediately after the refresh operation from an image signal and improve the image quality. Though FIG. 7 shows the two-dimensional sensor **801** of 3×3 pixels, it is preferable that more pixels are used.

Furthermore, it is allowed to perform the accumulation operation between the refresh operation and the read operation while light is irradiated. Furthermore, though details will be described later, it is allowed to restrict irradiation of light only to the time of accumulation operation as shown in FIG. 15C.

Furthermore, though imaging of a static image is described above, it is also possible to image a dynamic image by using the X-ray imaging apparatus of the first embodiment. In this case, it is preferable to set operation timing and voltage in accordance with the number of frames necessary for dynamic-image imaging.

Second Embodiment

Then, second embodiment of the present invention is described below. FIG. 11 is a circuit diagram showing the configuration of one pixel of the two-dimensional sensor of the radiation imaging apparatus (X-ray imaging apparatus) of the second embodiment of the present invention.

To image a dynamic image, it is necessary that a photoelectric conversion element always keeps stable sensitivity and dynamic range. Therefore, it is preferable to refresh pixels every frame. However, in the case of the structure of the first embodiment, refresh can be simultaneously performed only for all pixels. Therefore, a frame rate is lowered by the time of the refresh operation.

However, in the case of the second embodiment, a TFT **1004** for refresh is set every pixel. The gate of the TFT **1004** for refresh is connected to a gate line **1006** connected to a vertical driving circuit **1001**. Moreover, the source of the TFT **1004** for refresh is connected to the source of the TFT **216** and a refresh power supply **1005** is connected to the drain of the TFT **1004** for refresh. The refresh power supply **1005** can supply voltages V_{ref2} and V_r . In this case, the voltage V_r is the same voltage as that of the reference power supply V_r of the amplifier **401**. Moreover, voltage V_{ref2} is higher than that of the reference power supply V_r of the amplifier **401** and lower than the voltage V_s .

Furthermore, the second embodiment is provided with a control circuit **1007** for controlling the light source **601** and X-ray source **119** similarly to the case of the control circuit **604** of the first embodiment. The control circuit **1007** controls light emitting/no-light emitting of the light source **601** and generation of X-rays from the X-ray source **119**.

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By using the above configuration, the second embodiment performs refresh by using the TFT **1004** for refresh instead of changing voltages applied from the sensor bias line **218** and thereby refreshing the MIS-type photoelectric conversion element **217**.

When performing refresh by the circuit shown in FIG. 11, the voltage V_{com} is first supplied to the gate line **1006** to turn on the TFT **1004** for refresh. In this case, the control signal VRC is controlled so as to output the voltage V_{ref2} from the refresh power supply **1005**. As a result, the voltage V_{ref2} is supplied to the sensor bottom electrode layer **207** of the MIS-type photoelectric conversion element **217** through the TFT **1004** for refresh, the potential of the sensor bottom electrode layer **207** is lowered, and the band state same as the case of the refresh mode shown in FIG. 2C is realized.

Then, after supplying the voltage V_{ref2} sufficient for refresh, the control signal VRC is controlled to supply the voltage V_r to the TFT **1004** for refresh from the refresh power supply **1005**. As a result, when the voltage V_r is applied to the sensor bottom electrode layer **207** of the MIS-type photoelectric conversion element **217** through the TFT **1004** for refresh, the MIS-type photoelectric conversion element **217** becomes the photoelectric conversion mode.

Thereafter, by applying the voltage V_{ss} to the gate line **1006** and turning off the TFT **1004** for refresh, refresh operation is completed.

By performing this refresh operation, it is possible that each pixel can independently perform refresh and a pixel can be refreshed when the other line is being read.

Then, operations of one pixel constituted as described above are described by referring to FIG. 13. FIG. 12 is a timing chart showing changes of potentials of the points E and F in the pixel shown in FIG. 13. FIG. 13 shows the voltage ($V_e - V_f$) to be applied to the photoelectric conversion layer **209** together with the potential V_e of the point E and potential V_f of the point F when X-ray irradiation and refresh are repeated from immediately after a power supply is turned on.

The portion rising in “refresh” in FIG. 13 shows that the MIS-type photoelectric conversion element **217** is refreshed. Refresh in this embodiment is performed by turning on the TFT **1004** for refresh and changing voltages at the bottom electrode layer **207** side of the MIS-type photoelectric conversion element **217** as described above. Therefore, the timing of refresh is changed by the potential of the point F. The change of voltages of other portion is the same as the case of the first embodiment shown in FIG. 6. That is, also in the case of this embodiment, the principle of irradiating light from the light source **601** before performing imaging to restrain the fluctuation of sensitivity and setting the MIS-type photoelectric conversion element **217** to the saturation state is the same as in the first embodiment.

Then, a two-dimensional sensor (sensor unit) provided with nine above pixels (3×3 pixels) and its peripheral circuits are described. FIG. 13 is a circuit diagram showing the configuration of a two-dimensional sensor in which nine pixels shown in FIG. 11 are arranged like a matrix and its peripheral circuits.

In the case of the second embodiment, the TFT **1004** for refresh is set to each pixel and the two-dimensional sensor (sensor unit) **1002** is constituted compared to the first embodiment shown in FIG. 7. Moreover, the refresh power supply **1005** is added. Furthermore, not only three gate lines V_{g1} to V_{g3} but also the vertical driving circuit **1001** for driving the gate lines V_{gr1} to V_{gr3} (**1006**) are set instead of the vertical driving circuit **105**. That is, the vertical driving circuit **1001** is constituted so as to be able to separately drive the gate lines V_{g1} to V_{g3} for driving the TFT **216** for transfer

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and the gate lines Vgr1 to Vgr3 for controlling the TFT 1004 for refresh. Moreover, a refresh line for connecting the refresh power supply 1005 and TFT 1004 for refresh of each pixel is set. Other configuration is the same as the case of the first embodiment.

Then, the two-dimensional sensor 1002 constituted as described above and driving method and operations of its peripheral circuits are described by referring to FIG. 14. FIG. 14 is a timing chart showing operations of the two-dimensional sensor 1002 of the second embodiment.

First, by irradiating light from the light source 601 similarly to the case of the first embodiment, each pixel is set to saturation state. Thereafter, the two-dimensional sensor 1002 also starts the operation for imaging when X-ray irradiation is started by an operator.

The operation for imaging a dynamic image is described below.

First, the TFTs 216 for all pixels are turned off to irradiate X-rays while setting the MIS-type photoelectric conversion element 217 to the photoelectric conversion mode. As a result, electric charges proportional to the quantity of light emitted from a phosphor are accumulated in the MIS-type photoelectric conversion element 217 by receiving X-rays passing through an object and reaching the phosphor.

Then, the electric charges accumulated in the MIS-type photoelectric conversion element 217 are read from the two-dimensional sensor 1002. First, the control signal RC is set to high (Hi) to reset outputs of the AMP1 to AMP3 connected to the signal lines Sig1 to Sig3. Thereby, it is possible to remove electric charges accumulated in the integral capacitance Cf which become causes of noise and offset. Then, the amplifiers AMP1 to AMP3 are reset for sufficient time and then the control signal RC is set to low (La) to complete the reset operation.

Then, the voltage Vcom is supplied to the gate line Vg1 to turn on TFTs T11 to T13. When these TFTs are turned on, electric charges accumulated in the MIS-type photoelectric conversion elements S11, S12, and S13 are transferred to the amplifiers MP1 to AMP3 through the signal lines Sig1 to Sig3. Then, TFTs T11 to T13 are turned on by the time sufficient for transfer of electric charges and these TFTs T11 to T13 are turned off. Moreover, after proper time elapses after the TFTs T11 to T13 are turned off, the control signal SH is set to high (Hi) to make the sample-and-hold circuit 803 hold outputs of the amplifiers AMP1 to AMP3.

Thus, the read operation for one line is performed.

Electric charges sample-held by the sample-and-hold circuit 803 are serially transferred to the A/D converter 806 by the multiplexer 804 through the buffer amplifier 805 when reading the next line.

Then, read pixels are refreshed when reading the next line. This refresh operation is described above. However, as shown in FIG. 14, because the gate lines Vgr1 to Vgr3 of the TFT 1004 for refresh of pixels are shared by right and left pixels, refresh is performed one horizontal line by one horizontal line.

By performing the above read operation and refresh operation for all lines, electric-charge transfer and refresh of all pixels are completed. Moreover, it is possible to image a dynamic image by repeating the driving in FIG. 15. That is, because the read operation and refresh operation required to image a dynamic image can be continuously performed every one horizontal line, it is possible to improve a frame rate.

It is not always necessary to make the timing for turning on/off the TFT 1004 for refresh coincide with turn-on/off of the TFT 216 for transfer at the next line. Moreover, it is preferable to select each power supply voltage so as to satisfy

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characteristics of the MIS-type photoelectric conversion element 217 and TFT 216, transfer capacitance requested as an imaging apparatus, and dark current.

Moreover, in the above description of operations, imaging of a dynamic image is described. However, it is also possible to image a static image by using the X-ray imaging apparatus of the second embodiment. In this case, it is only necessary to use the TFT 1004 for refresh by turning it off. Therefore, it is also possible to image a static image after imaging a dynamic image. This sequence is a sequence to be generally performed at the time of see-through imaging of a digestive system. In this case, it is only necessary to image a dynamic image (see-through) along the timing chart in FIG. 14 and when imaging a static image, turn off the TFT 1004 for refresh, and perform operations along the timing chart in FIG. 10.

In this case, determination of the saturation state by the control circuit 604 or 1007 is described below. As described above, irradiation of light stops each pixel after bringing it to a saturation state. It is allowed to perform this control in accordance with elapsed time. However, it is also possible to monitor the output fluctuation of the MIS-type photoelectric conversion element 217 at the time of light irradiation and perform the control in accordance with the above result. FIGS. 15A to 15D are timing charts respectively showing the relation between driving and output of a two-dimensional sensor when light is irradiated.

FIG. 15A shows an output of a two-dimensional sensor when repeating driving for continuously performing read a certain number of times after performing refresh. As shown in FIG. 15A, when repeating read (F1 to Fn) after refresh, an output of the two-dimensional sensor is slowly lowered. This is because electric charges are slowly accumulated in a photoelectric conversion element and sensitivity is lowered. Therefore, by monitoring the difference between outputs of the frame F1 and frame Fn, it is possible to determine irradiation pause time of light. For example, it is allowed to stop irradiation by using that the output difference between the frame F1 and the frame Fn reaches a certain specified value as a condition. Moreover, it is allowed to stop irradiation by using that the output difference between the frame F1 and the frame Fn becomes stable, that is, the output difference becomes smaller than the specified value as a condition. For a photoelectric conversion element to reach a saturation state and for an output of a two-dimensional sensor to become very small, operations of several frames to several tens of frames are necessary. The necessary number of frames depends on the voltage Vs and the dose of light.

Though FIG. 15B is an illustration showing driving and output of a two-dimensional sensor when light is irradiated similarly to the case of FIG. 15A, it is different from FIG. 15A in that refresh and read are alternately repeated. In the case of this driving method, it is only necessary to monitor a signal of the frame F1 and stop irradiation of light by using that the change of signals becomes smaller than a specified value as a condition.

Moreover, when the light source 601 has a preferable response characteristic, as shown in FIG. 15C, it is allowed to perform accumulation operation between refresh and read and use a driving method for making the light source 601 emit light during accumulation operation. According to this driving method, it is possible to accurately monitor the output fluctuation of a two-dimensional sensor. Also when using this driving method, it is only necessary to monitor the signal of the frame F1, for example, and stop irradiation of light by using that the change of signals becomes smaller than a specified value as a condition.

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Moreover, as shown in FIG. 15D, it is allowed to perform the read operation which does not irradiate light after read after irradiation of light and monitor an output obtained by subtracting the last signal from the signal at that time, that is, the difference value between the frame F1 and the frame F2. According to this method, a component serving as a dark current of a photoelectric conversion element and the factor of an error such as a residual image are removed and it is possible to monitor output fluctuation at higher accuracy. When using this driving method, it is only necessary to stop irradiation of light by using that a difference value becomes smaller than a specified value as a condition.

Then, the embodiment of an X-ray imaging device is described below. FIG. 16 is an illustration showing an example of an embodiment of the X-ray imaging apparatus of an embodiment of the present invention. A glass substrate 1403 on which a phosphor 1402 and a two-dimensional sensor are formed is housed in a housing 1401 made of aluminum alloy or magnesium alloy. An IC 1406 including the signal amplifying circuit 802, sample-and-hold circuit 803, and multiplexer 804 is connected to a glass substrate 1403 through a tape carrier package (TCP) 1405. Moreover, the IC is connected to a relay board 1407, A/D board 1408, and system board 1409 through the TCP 1405. The relay board 1407 delivers a signal from the IC 1406, various power supply, and a control signal. The A/D board 1408 includes the A/D converter 806 and converts a signal from a two-dimensional sensor into a digital signal. The system board 1409 controls the two-dimensional sensor and various boards. Moreover, the boards are electrically connected by a signal cable 1410. Moreover, the boards are fixed by a support substrate 1404. An imaging unit is constituted of the above boards.

A light source 1412 corresponding to the light source 601 is further included in the housing 1401. A light guide plate 1411 is set on a light source tray 1416 and a light source 1412 is set to the both ends of the light guide plate 1411. Moreover, a reflection sheet 1413 for completely sending the light emitted from the light source 1412 toward the glass substrate 1403 is set between the light guide plate 1411 and the light source tray 1416. Furthermore, a prism sheet 1415 and diffusion sheet 1414 for uniformly diffusing the light from the light guide plate 1411 are set. Thus, a light source unit is constituted. Though it is preferable to use an LED by which light emission is easily turned on/off as the light source 1412, it is allowed to use a cold cathode.

In the case of an X-ray imaging apparatus thus constituted, light 1418 emitted from the light source 1412 propagates through the light guide plate 1411 and is reflected immediately upward by a reflection pattern set in the light guide plate 1411 in the process of propagation. In this case, the light to be leaked to the downside of the light guide plate 1411 is returned to the light guide plate 1411 by a reflection sheet. Then, the light reflected immediately upward and the light leaked to the upper portion of the light guide plate 1411 by the light guide plate 1411 are diffused by the prism sheet 1415 and diffusion sheet 1414 and uniformly irradiated to the glass substrate 1403. The reflection sheet 1413, diffusion sheet 1414, and prism sheet 1415 are not always necessary. It is allowed to use them according to necessity.

Moreover, as shown in FIG. 17, it is allowed to use a surface-emission device 1501 such as an organic EL or inorganic EL. In this case, a diffusion sheet 1502 is set on the surface-emission device 1501 so that the light 1503 propagates through the inside of the sheet 1502. Furthermore, it is allowed to use a device in which LEDs 1602 are two-dimen-

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sionally arranged on a print substrate 1601 as a surface-emission device 1501 as shown in FIG. 18.

Then, an irradiation example of the X-ray imaging apparatus of an embodiment of the present invention to an X-ray-image imaging system is described. FIG. 19 is a schematic view showing the configuration of an X-ray-image imaging system.

X-ray 6060 generated by an X-ray tube 6050 (X-ray source 119) passes through the chest region 6062 of a patient or subject 6061 and enters an image sensor 6040 including an X-ray imaging apparatus. The information on the inside of the body of the patient 6061 is included in the X-rays that have entered. A scintillator (phosphor) emits light correspondingly to the entrance of the X-rays 6060, the photoelectric conversion element of a sensor panel photoelectrically converts the light, and electrical information is obtained. The image sensor 6040 outputs the information to an image processor 6070 as an electrical signal (digital signal). The image processor 6070 serving as image processing means applies image processing to the received signal and outputs the signal to a display 6080 serving as display means of a control chamber. A user observes an image displayed on the display 6080 and can obtain the information on the inside of the body of the patient 6061. The image processor 6070 also has the function of control means and is able to change the imaging mode of dynamic image/static image or control the X-ray tube (X-ray generator) 6050.

Moreover, the image processor 6070 transfers an electrical signal output from the image sensor 6040 to a remote place through transmission processing means such as a telephone line 6090 and is able to display the signal on display means (display) 6081 present at another place such as a doctor room. Furthermore, the image processor 6070 stores an electrical signal output from the image sensor 6040 in recording means such as an optical disk and a remote-place doctor can perform diagnosis by using the recording means. Furthermore, it is possible to record the electrical signal in a film 6110 by a film processor 6100 serving as recording means. Furthermore, the doctor can enlarge or reduce an image displayed on the display 6081, image-process the image to a desired density, and performs the processing such as the difference with another image, and perform diagnosis in accordance with them.

An embodiment of the present invention can be realized when, for example, a computer executes a program. Moreover, means for supplying a program to a computer, for example, a computer-readable recording medium such as a CD-ROM storing the program or transmission medium such as the Internet for transmitting the program can be applied as an embodiment of the present invention. Moreover, it is possible to apply the above program as an embodiment of the present invention. The above program, recording medium, transmission medium, and program product are included in the scope of the present invention.

Capable of Exploitation in Industry

The present invention is preferably used for a radiation imaging apparatus preferably used for medical-care diagnosis and industrial nondestructive inspection.

While the present invention has been described with reference to exemplary embodiments, it is to be understood that the invention is not limited to the disclosed exemplary embodiments. The scope of the following claims is to be accorded the broadest interpretation so as to encompass all such modifications and equivalent structures and functions.

What is claimed is:

1. A radiation imaging apparatus comprising:
 - a sensor unit for acquiring an image signal from radiation, wherein said sensor unit includes a pixel having an MIS-

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type conversion element, and wherein said MIS-type conversion element includes a first electrode, a second electrode, a photoelectric conversion layer arranged between said first and second electrodes and an insulating layer arranged between said first electrode and said photoelectric conversion layer;

a driving circuit unit for driving said sensor unit to perform a first operation such that the MIS-type conversion element generates an electron-hole pair according to incident radiation or light, a second operation for reading an electric signal based on an electron or a hole from said sensor unit, and a third operation for removing a part of the electrons or the holes accumulated at an interface between said photoelectric conversion layer and said insulating layer;

a light source for emitting light onto said MIS-type conversion element;

a power source for supplying a first voltage or a second voltage between said first and second electrodes, wherein the first voltage is supplied during the first and second operations, and the second voltage is supplied during the third operation; and

a control unit for controlling said driving circuit unit, said light source and said power source, wherein

before irradiating the radiation onto said sensor unit, said control unit controls said driving circuit unit, said light source and said power source so as to repeat, at least twice, a set of first and second operations with light being emitted from said light source onto said MIS-type conversion element, until a predetermined voltage is applied to the photoelectric conversion layer in a succeeding first operation after a performance of the third operation, and

so as to perform the third operation after the second operation of the final set of the first and second operations.

2. The radiation imaging apparatus according to claim 1, wherein said pixel includes a switch element connected to said first electrode, said switch element is a transistor having gate, source and drain electrodes, one of said source and drain electrodes is connected to said first electrode, and said gate electrode is connected to said driving circuit unit.

3. The radiation imaging apparatus according to claim 2, further comprising a signal amplifying circuit connected to the other of said source and drain electrodes of said switch element,

wherein said power source includes a reference source for supplying a reference voltage to said signal amplifying circuit.

4. The radiation imaging apparatus according to claim 3, wherein said power source further includes a bias source for

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supplying a third voltage to said first electrode for supplying the first voltage between said first and second electrodes.

5. The radiation imaging apparatus according to claim 4, wherein said bias source supplies a fourth voltage to said first electrode for supplying the second voltage between said first and second electrodes.

6. The radiation imaging apparatus according to claim 4, wherein

said pixel includes a further switch element connected to said first electrode, different from said switch element, said further switch element is a transistor having gate, source and drain electrodes, one of said source and drain electrodes of said further switch is connected to said first electrode, and said gate electrode of said further switch is connected to said driving circuit unit,

said power source further includes a further power source connected to the other of said source and drain electrodes of said further switch, and

said further power source supplies a fourth voltage to said second electrode for supplying the second voltage between said first and second electrodes.

7. A radiation imaging system comprising: the radiation imaging apparatus according to claim 1; and a radiation source for irradiating the radiation.

8. A controlling method for controlling a radiation imaging apparatus, wherein the apparatus comprises a sensor unit for acquiring an image signal from radiation, wherein the sensor unit includes a pixel having an MIS-type conversion element, the MIS-type conversion element includes a first electrode, a second electrode, a photoelectric conversion layer between the first and second electrodes and an insulating layer arranged between the first electrode and the photoelectric conversion layer, and a light source for emitting light onto the MIS-type conversion element, said method comprising:

a first step of repeating, before irradiating the radiation onto the sensor unit, at least twice, a set of a first operation such that the MIS-type conversion element generates an electron-hole pair according to incident radiation or light and a second operation for reading an electric signal based on an electron or a hole from the sensor unit, with light being emitted from the light source onto the MIS-type conversion element, until a predetermined voltage is applied to the photoelectric conversion layer in a succeeding first operation after an operation for removing a part of the electrons or the holes accumulated at an interface between the photoelectric conversion layer and the insulating layer; and

a second step of performing the operation for removing, after the first step.

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